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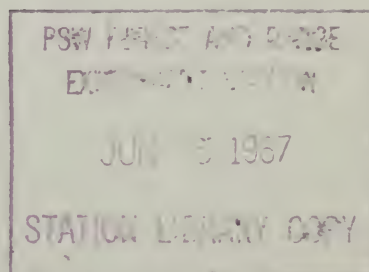
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fpl 1965

ANNUAL REPORT of RESEARCH at the FOREST PRODUCTS LABORATORY



U. S. DEPARTMENT of AGRICULTURE | FOREST SERVICE



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fpl 1965



McGARVEY CLINE, 1879-1965

First Director of the U. S. Forest Products Laboratory, 1910-12. Mr. Cline, as a Forest Service research engineer, conceived the idea of a national laboratory for research on wood and its products. He negotiated the agreement with the University of Wisconsin, signed by Chief Forester Gifford Pinchot, that led to the Laboratory's founding at Madison in 1910. This photo of Mr. Cline was taken several years ago in his home in Jacksonville, Fla.

FPL 1965

*Annual Report of Research at the
Forest Products Laboratory*

FOREWORD

Accomplishments at FPL during 1965 focus attention on two major areas. Both are of major significance in furthering our goal of maintaining and creating new markets for wood. The year was one of outstanding research accomplishment which should stimulate optimism for the future growth of the forest industries. Actual construction was started on the first phase of a program to provide urgently needed new research facilities at the Laboratory.

Construction of the new pilot plant and adjoining office-laboratory building for wood fiber products investigations began in September. By the end of the year the buildings were "out of the ground" and the pilot plant ready for the laminated wood arches. The Wood Chemistry building shown on the cover of our 1964 Annual Report fell victim to rising costs and must await additional funding. We look forward with eager anticipation to the new and vital research which can be undertaken with completion of current construction early in 1967 and with implementation of the planned future construction to follow.

Both producers and users of wood products have already evidenced a keen interest in the research reported during the year. Among noteworthy achievements were the following:

- A new concept of house design based on six components planned for mass production and fast site assembly and made principally from conventional wood building materials.
- A promising new method of predicting, by computer, yields of cuttings possible from standard hardwood lumber grades, specifying most economical grades and providing sawing instructions.
- A new natural finish system of exceptional promise for exterior service.
- Red oak wall paneling and flooring produced from low-grade logs and uniquely colored by a new press-drying process.
- An alkaline sulfite chemimechanical pulping process for producing brighter groundwood-type pulps from hardwoods.
- Two processes for recovering chemicals from spent liquors of neutral sulfite semichemical pulping processes, thereby improving process economy and reducing pollution.
- Establishment, for industry guidance, of thermal insulating properties of fiberboards and particle boards.
- A new board product consisting of pulping-size wood chips economically resin-bonded together in thicknesses suitable for roof decking or ceiling tile.
- Publication of research findings of two timber density surveys, one dealing with southern pines and the other with western woods.
- Definite evidence that flashover of hot combustible gases to fresh oxygen sources is a primary cause of fire spread in building interiors.

These and other examples of research progress are discussed in this Annual Report for 1965. A complete list of the year's publications is appended.



EDWARD G. LOCKE

Director

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THE YEAR IN GENERAL

The year 1965 witnessed an unusually broad mix of activities at FPL. A start on construction of the first major new facilities in 33 years was of course the most obvious and attention-commanding element. Research activities, however, also set a brisk pace and produced solidly substantial results. And staff participation in scientific and technological activities throughout the forest products world was maintained at a high level.

Years of planning and preparation reached a climax in June with the award of a construction bid for a new pilot plant and laboratory-office building for research in wood fiber products to the Orville E. Madsen and Son Company of Minneapolis. The building site just north of the present Laboratory buildings, acquired from the University of Wisconsin 2 years previously, was soon churning with the activities of earth-moving machinery and crews of workmen as footings were dug, foundations poured, and forms for lower walls of the superstructure hammered together.

By year's end, all was in readiness for the raising of the first laminated wood arches of the pilot plant—massive three-section structural elements that would extend 50 feet above their concrete bases and span the full 60-foot width of the 460-foot-long structure. The arches, in fact, had arrived from the plant of the manufacturer protected with waterproof paper from snow and ice. Each leg weighed 8,200 pounds and contained 4,300 board feet of southern pine 1-inch boards dressed to a final width of 11 inches. Connecting them at the top would be equally massive beams each weighing 3,800 pounds and containing 2,000 board feet of lumber. Thus, each arch weighed 20,200 pounds and required 12,600 board feet of lumber.

There will be 11 such arches spaced 20 feet on centers along almost half the length of the building. Another 13 smaller ones will complete the structure's main framework, anchored to bases at the second-floor level, each made up of 7,250 board feet of lumber and weighing 13,800 pounds.

The enclosing skin supported by these arches will consist of lumber roof decking and stressed-skin wall panels of plywood glued to lumber frames. The exterior face of the panels will be covered with a polyvinyl fluoride film and the interior face with resin-treated paper—thus constituting probably the world's only laboratory building for pulp and paper research with a wall-papered interior! The tough kraft-paper skin, however, will have a utilitarian rather than an esthetic function, providing an excellent base for paint.

The laboratory-office building extending at right angles from the South end of the pilot plant will be somewhat smaller, 167 feet long, 51 feet wide, and four stories high. It will house laboratories and offices for research in wood fiber products. A third building that had been planned for wood chemistry research was

eliminated when construction costs proved too high for the funds available. Construction of this building will therefore depend upon future appropriation of additional funds by the Congress.

Two unusual awards were conferred upon staff members during the year. Dr. Edward G. Locke, Director, was presented the 1965 American Lumber Industry Applied Research Award by the National Lumber Manufacturers Association (since changed to National Forest Products Association) at Washington, D.C., on May 12.

Gardner H. Chidester, chief of the Division of Wood Fiber Products Research, was given the Distinguished Service Award of the U.S. Department of Agriculture by Secretary Orville L. Freeman.

The award citation presented to Dr. Locke read:

"Dr. Edward G. Locke, representing the finest ideals of applied research during the past year, merits the recognition and respect of the National Lumber Manufacturers Association. He is therefore singled out from among those individuals, firms, and organizations which in the opinion of the American lumber industry have materially enhanced the reputation of the industry, profession, and nation they serve, to be the 1965 recipient of an American Lumber Industry Award recognizing superior accomplishment in the finest traditions of the nation's oldest manufacturing industry, and is designated to receive the 1965 Applied Research Award."

Mr. Chidester was cited for:

"Exceptional technical accomplishments and direction of the pulp and paper research program of the Forest Service, resulting in extensive economic contributions to the United States and many foreign countries."

A sobering reminder of the swift passage of time came in early May when news was received of the death April 29 of McGarvey Cline, first director of the Forest Products Laboratory. Mr. Cline is acknowledged to have conceived the idea of centralizing Forest Service wood research, then conducted cooperatively with a number of universities from coast to coast, at a national Forest Products Laboratory. His aim was to achieve efficiency, economy, and much closer collaboration among scientists skilled in the various disciplines essential to a balanced research program in forest products. He negotiated with a number of institutions interested in providing facilities for such a laboratory, then without precedent in the world.

Mr. Cline was primarily responsible for the arrangement with the University of Wisconsin that provided a building, heat, light, and other assistance for a nucleus of some 45 Forest Service research workers who gathered at Madison under his direction in 1909. The new laboratory was formally dedicated in 1910,



Glistening with fresh glue, boards are assembled one on another at laminated arch manufacturing plant. M 129 947



Workmen clamp assembly of freshly glued boards against form built to curvature of laminated arches for pilot plant.

M 129 958

2

Laminated arches and sidewall girts wrapped in waterproof paper are unloaded at snow-covered building site just before Christmas 1965.





The 1965 Applied Research Award of the National Lumber Manufacturers Association was presented to Dr. Edward G. Locke, left, FPL director, by Mark Townsend, president of the association.

and Mr. Cline remained as director until 1912, when he entered private business. For many years, until his death, he resided in Jacksonville, Fla.

Highlighting the year's international associations was a trip by Dr. Locke to Australia where he presided over a meeting of Section 41, Forest Products, of the International Union of Forestry Research Organizations in Melbourne. Subject of the conference was research in wood quality, sawing and machining, and wood and tree chemistry.

Coleman L. Vaughan, FPL timber quality specialist, also participated, presenting one of five papers by other FPL staff members. Dr. Locke also conferred en route with forest products research workers and manufacturers in New Zealand, Japan, The Philippines, and Hawaii.

Another highlight was the consultant's role taken by Mr. Chidester at a conference on pulp and paper development in Africa and the Near East held in March at Cairo, Egypt.

Research progress was distinguished by a number of accomplishments during the year. Among the more outstanding was the engineering development of a new system of house components made of conventional materials. FPL housing and building research is not, however, limited to structural design studies. Among other noteworthy developments in this area were the finding of a highly promising natural finish system for use on wood siding by a wood chemist and the evolution

of a new concept for interior wall paneling and flooring material featuring a novel approach to the physics of wood drying.

In fact, an analysis of FPL research by the staff committee on housing research revealed that, of 37 projects and 319 studies under way at the time, 17 projects and 102 studies related directly to housing and light-frame construction. Four of the five technical divisions shared in housing research, which embraces the broad areas of environment and conditions of use; improved protection from decay, insects, fire, and the elements; development of new materials; improved design procedures, and building components and new building techniques.

As national headquarters for Forest Service research on wood, FPL serves governmental agencies, industry, and the general public in many ways. Its work is complemented by projects and studies on forest products at the nine Forest Experiment Stations. In general, FPL research is aimed at developing knowledge that is adaptable or applicable anywhere in the United States at the least possible cost.

This report presents summaries of research progress at FPL under five main headings corresponding to the names of its five technical research divisions: Wood Engineering Research; Wood Quality Research; Wood Fiber Products Research; Wood Chemistry Research; and Solid Wood Products Research.

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Secretary of Agriculture Orville L. Freeman, left, presents the Distinguished Service Award of the U. S. Department of Agriculture to Gardner H. Chidester, Chief, Division of Wood Fiber Products Research.

M 128 949



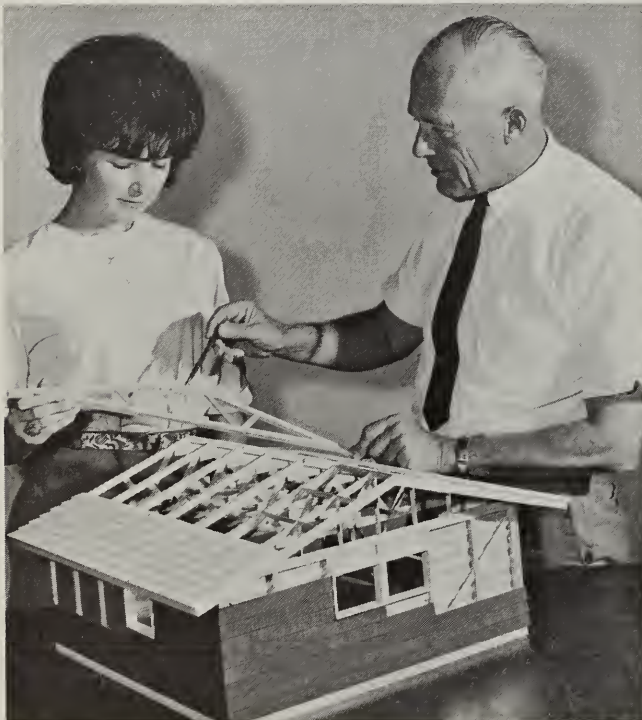
WOOD ENGINEERING RESEARCH

Highlighting FPL engineering research achievements during 1965 was completion of the basic concept for a new componentized wood-frame house fabrication system. The concept represents several years of experimentation with various materials and engineering design ideas. From these were evolved six primary structural components for walls and roof of a house produced essentially from conventional wood building materials.

Among other significant advances were:

1. Establishment of thermal insulating values for new fiberboard and particle board building materials.
2. Acoustical research to compare alternate methods of determining sound reflectance of building material and participate in a round-robin evaluation of calibration materials with other laboratories.
3. Acquisition of data on equilibrium moisture content of new building materials to establish their dimensional stability and related properties.
4. Introduction to U.S. industry of a new concept for deriving working stresses by means of surveys and destructive testing of large representative samples of lumber of various species and grades.
- 4 5. Start of a long-term evaluation of wood pole and truss construction.

Engineer L. O. Anderson points out to Secretary Judy Kent a design feature of dual-chord truss he designed as one component of new FPL housing system. M 129 401



Progress on these and other studies is detailed in the following paragraphs.

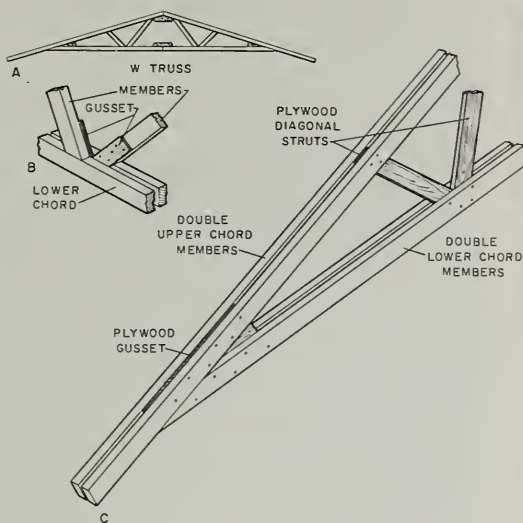
Nu-Frame House Design

The house design componentized from conventional building materials has been named Nu-Frame by its principal designer, FPL Engineer L. O. Anderson. Objectives in its design were:

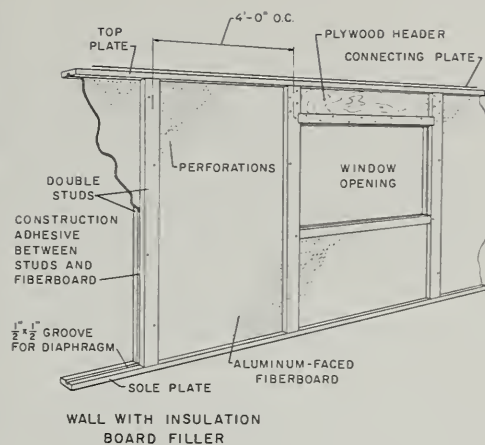
1. To realize as fully as possible the savings inherent in factory-made components and rapid assembly at the building site.
2. To combine materials and assemblies in an integral structural concept providing built-in sound-proofing and other advanced features.
3. To utilize a new plastic material of outstanding durability as the weather surface of a lumber-plywood roofing component.
4. To exploit to the fullest extent possible the advantages of economy, structural rigidity, and completely flexible use of space inherent in trussed roof construction.
5. To employ the benefits of advanced engineering research that permits expanded use of relatively low-cost and plentiful grades of lumber.

The six components comprising walls, partitions, and roof are designed for erection on conventional lumber-joist or concrete slab-on-ground floor. They are:

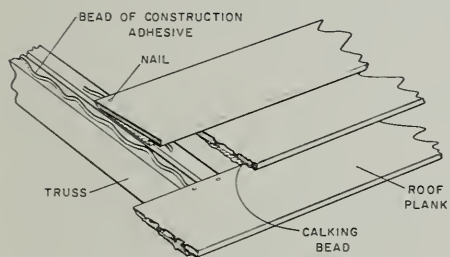
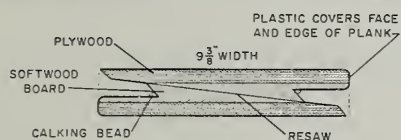
1. A wall framing system with a unique central stiffening diaphragm of building fiberboard nailed between pairs of two-by-four studs that stand flatwise to the wall surface at 4-foot intervals.
2. The diaphragm itself, which performs a triple duty of stiffening the wall and furnishing both heat and sound insulation. The fiberboard, a good insulator in itself, is faced on both sides with aluminum foil for added reflective heat insulation. Sound deadening is achieved with patterns of 3/16-inch-diameter holes on the faces that act as soundtraps.
3. An interior wall surface component consisting of 4- by 8-foot sheets of 1/4-inch-thick foil backed gypsum board reinforced with 1- by 6-inch boards spaced 6 inches apart. The foil backing of the gypsum board provides a vapor barrier and adds insulation.
4. The exterior covering component combines wall sheathing with siding. Sheathing boards are first edge-glued together to multiples of finished 12-inch width, then rip-sawed to that width plus allowance for one tongue, the opposite edge being grooved. Bevel siding with a semishiplap bottom (thick) edge is then glued to the sheathing. The tongue-and-grooved sheathing edges interlock adjoining courses when the component is in-



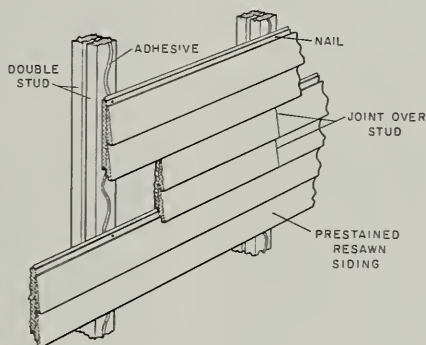
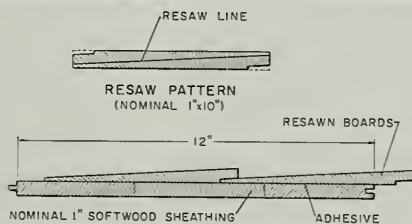
ROOF TRUSS COMPONENT



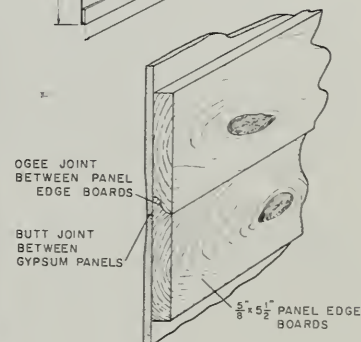
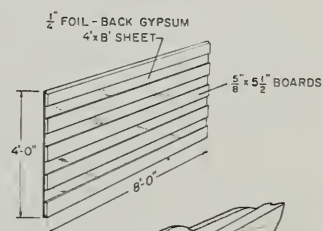
WALL FRAMING AND DIAPHRAGM COMPONENTS



PLASTIC ROOFING COMPONENT



EXTERIOR SHEATHING-SIDING COMPONENT



INTERIOR WALL COMPONENT

Components of new FPL housing system are designed for factory production and rapid site assembly from conventional building materials. M 129 529 M 129 526 M 129 525 M 129 524 M 129 527

stalled, and no face nailing is necessary.

5. The fifth component is a roof truss of unique design employing double chords and single struts and gussets. The struts and plywood gussets are sandwiched between the two-piece chords and bonded to them with glue. Only one-half as many are needed to support a roof as when conventional single-chord trusses are used, and the double-chord trusses are simpler to make because they need not be turned over to fasten gussets on both sides.

6. The roofing component is also a glued-up sandwich of a 1-inch board and two pieces of plywood. This sandwich is resawn on a diagonal through the thickness, so that two beveled pieces are produced. The thick edge of each piece is back-notched to accept snugly the thin edge of another when installed on a roof. Face and edges of each piece are covered with an asbestos-backed polyvinyl fluoride film, which will be the plastic weather surface of the roof.

In the assembly of components into walls and roof,

a commercial adhesive applied with a calking gun is used extensively. This not only produces a more uniform bond but reduces greatly the number of nails necessary.

For example, the foot-wide siding-sheathing component requires only one nail per stud because of the continuous ribbon of glue between stud and sheathing and the firm tongued-and-grooved joint between siding courses. The nail is driven through the upper lip of the sheathing and hidden by the overlapping lower edge of the siding course above it.

Roofing is similarly "blind nailed" with two nails at each truss, the nails being hidden by the overlap of the next higher course of roof component.

The inner wall surface component of gypsum sheets and spaced boards is nailed like conventional dry wall to studs, two nails through each board. The nail heads are speckled with a plaster paste, and joints between sections are taped. Anderson's design calls for horizontal installation of the 4- by 8-foot sections. An alternate design is being developed for vertical installation.

Despite the many design and structural innovations in walls and roof, the finished house is planned to have a completely conventional appearance. Thus far, only a ranch-style model has been considered.

All component parts have been built in the Laboratory to full scale and meticulously tested. In all essential strength and structural requirements, Anderson said, they at least equal comparable parts of conventional light-frame house construction with joists, rafters, and studs spaced 16 inches on centers.

Strength and rigidity of the wall frame and roof truss, as assessed in laboratory experiments, easily exceed requirements for conventional wood-frame house construction. A wall section with the diaphragm component in place was compared with a conventional wall panel framed with studs 16 inches on center and covered on one side with 1- by 8-inch sheathing-grade boards. The section was 2.2 times as rigid and 1.4 times as strong as the conventional panel when racked by a force applied at one upper corner and resisted at the diagonally opposite corner. This loading simulates a wind load bearing on a wall at right angles to the wall under test.

The roof trusses were designed for a roof load of 30 pounds per square foot over a 26-foot span. Total design load per truss is thus about 3,100 pounds. The conventional stiffness requirement for a ceiling is a deflection at midspan not greater than 1/360 of the span. All double-chord trusses with the familiar W strut pattern deflected far less under the design load for 4-foot spacing, within a range of 1/1200 to 1/1800 of the span.

Watertightness of the plastic-surfaced roof has been closely checked for about 2 years on an experimental roof section exposed outdoors. No seepage of water has been observed between courses, which were sealed with a rubber-base calking compound along the joints

when installed. Butt joints between sections of roof component in each course had been similarly sealed and taped with a polyvinyl fluoride tape.

Plans call for construction of a full-scale prototype for further evaluation of the system.

House Design for Hurricanes

Engineering reasons why some wood-frame structures survive intact such holocausts of nature as hurricanes and earthquakes while others collapse are set forth in a new Forest Service publication issued jointly by FPL and the Southeastern Forest Experiment Station. Authors are L. O. Anderson, FPL engineer, and Walton R. Smith, assistant director of the Station.

The authors base their conclusions about the superiority of well built wood-frame houses on years of studying the devastating forces erupted by hurricanes, tornadoes, and earthquakes. The study results were further substantiated by observations of Hurricane Betsy's destruction in Florida and Louisiana in September 1965.

Houses that resist successfully the forces of wind and earth shocks have certain structural superiorities in common, the report notes.

"The most severe damage to structures in hurricanes is caused when foundations fail or the structure is torn loose from its foundations. Next in severity is roof failure, caused by improper ties between the walls and the roof. Less severe, but causing tremendous monetary loss, are failures in roofing materials, failures in siding, broken windows, loss of porches, garages, steps, chimneys, and minor appurtenances such as television antennas."

Recommended types of foundations and methods of fastening foundations, walls, and roofs securely together are described and illustrated in the report. Superior ways of bracing and sheathing buildings, and types of fastenings best suited for the job, are also recommended. One section stresses advantages of pole-type construction.

Pole-and-Truss Structure

An experimental structure framed with poles and roof trusses of several designs was the first building erected in the new FPL Building Research Park, land for which became available for this use in 1965. Each pole and truss was evaluated for strength and stiffness before being installed; and as each structural part was connected with the rest, its contribution to structural rigidity of the whole was measured. Thus it is hoped to gain data indicating whether, as some contend, the capability of a structure to withstand forces is greater than can be calculated strictly on the basis of the properties of its component parts. Trusses are of conventional W design but varied as to materials used, some being made of hardwood and others of softwood species, with gusset plates of plywood or hardboard glued, nailed, or bolted in place. Truss design and performance will be evaluated under long-time dead load service conditions.

Also included in the structure for comparative eval-



Slant-leg rigid frame is placed on foundation by workmen building new pole-truss experimental structure in FPL Building Research Park

uation purposes are several slant-leg rigid frames made of double 2 by 12's and plywood gussets.

Meanwhile, FPL staff members are cooperating with the American Society of Agricultural Engineers and the American Society for Testing and Materials in the development of standards for poles used in building construction.

Lumber Research

Utilizing new methods of measuring the stiffness and strength of full-size dimension lumber in sizes commonly used in light-frame buildings, FPL research engineers have demonstrated that reliable working stresses can be established in this manner for various grades and species of lumber. The procedure was used

Crane lowers truss into place in experimental pole-truss structure for long-time dead loading evaluation.



to study six grades and four sizes of southern pine dimension lumber obtained in 19 producing States—nearly 2,000 pieces in all. Purpose of the study was to evaluate the grade-strength properties as they relate to load sharing and the possibilities of grading the southern pines nondestructively with mechanical proof-load stress rating machines.

The study material compared favorably in bending and compression-parallel-to-grain strength with the requirements of its grade; stiffness, was also related to structural grade. The relation of strength to stiffness, on which machine grading is based, was not quite as good as that previously observed in the western species.

Working stresses for lumber are conventionally computed from strength data obtained by testing small specimens of clear wood; to these data various limiting factors are applied. While this technique has definite advantages, such adjustments involve considerable judgment and experience. Strength data obtained directly from representative samples of grades and species offer another approach to the derivation of working stresses—provided, of course, that the data are reliable. New FPL methods of measuring tensile and comprehensive strength of full-size framing members (see 1964 Annual Report) have proven highly useful for obtaining such data.

In a related study, conducted in cooperation with the National Cargo Bureau, Inc., an agency of the Marine Cargo Insurance Writers, working stresses and rules were developed for selection of timbers and heavy planking used to control shifting of bulk grain cargoes in ocean freighters. Structural failures in ungraded material of unspecified species had resulted in loss of at least one vessel.

Nondestructive testing has tremendous potential. It has been estimated that, with proper development through research, sound methods of evaluating lumber could increase the total amount of usable strength by 20 percent. Based on present production, this would represent a product value of \$200 million per year. The value of other wood-base materials susceptible to nondestructive testing would be similarly enhanced.

Design Criteria

A constantly voiced need of structural lumber producers is for more precise design criteria. Lumbermen, plywood manufacturers, and producers of laminated structural members all agree that more exact knowledge of the behavior of wood in a structure is necessary for more economical and efficient construction. FPL research conducted to meet this need is based on the development of theoretical criteria substantiated by limited experimental investigation. New mathematical concepts and computer approaches afford promising means of developing such criteria.

Typical of the need for better design criteria is the lack of precise knowledge for evaluating the true influence of depth upon the strength of bending members. Available design criteria are based on limited

experimental data obtained from solid wood beams up to about 16 inches deep. The laminating industry, which can produce beams of any desired depth, is especially affected. Numerous approaches to the problem have been studied and rejected.

Recently a "weakest link" theory has been evolved that is now being explored experimentally. The theory is based on the statistical distribution of small defects that can occur more frequently in large beams than in small ones. Thus, the larger the beam, the greater the chance that a low-strength element or localized source of weakness will be present. Available experimental data are in complete agreement with the theoretical analysis. In cooperation with the National Forest Products Association, the laminating industry, and the Association of American Railroads, experiments will be conducted in the coming year on laminated beams 31½ inches deep and 50 feet long. Data obtained will be analyzed to determine whether the theory remains applicable for beams of this depth.

Completion of a study of wood-stringer bridges has led to a recommendation to the American Association of State Highway Officials that design stress criteria for maximum stringer shear in its Specification for Highway Bridges be modified. The present criteria for shear are over-conservative, the study showed. It was recommended that the AASHTO specification formula for load distribution to interior stringers for maximum external shear be modified from the present

$$\frac{P}{2} \left(\frac{S}{N} + 1 \right)$$

to

$$\frac{P}{2} \left(\frac{S}{N} + 0.6 \right)$$

The study showed no need to change existing design criteria for outside stringers in a bridge. Bridge engineers of the Forest Service Division of Engineering cooperated in the study.

From mathematical analyses, stability criteria were developed for determining the stabilizing influence of a lumber deck on thin, deep, widely spaced beams subject to lateral buckling. In the analysis, the deck was treated as a shear beam whose stabilizing influence, derived from its shear rigidity, is quantitatively accounted for by a dimensionless parameter in linear differential equations for predicting lateral buckling loads. Stability criteria were obtained for (1) a simply supported beam uniformly loaded; (2) a simply supported beam under constant bending moment; (3) a uniformly loaded cantilever; and (4) an end-loaded cantilever.

Hardboard Design Data

Five years of FPL research on the basic strength properties of hardboards will by next year have re-



Technician William Brewer adjusts grips of apparatus for testing tensile strength of particle board specimen.
M 124 984

sulted in the industrial use of structural grades with assigned design stresses in flexure, tension, compression, and shear—thereby opening new engineering uses for this type of panel building product. The investigation included more than 12,000 evaluations of hardboard under different moisture and loading conditions to establish the basic strength values now being used by the hardboard industry to assign working stresses for guidance of architects and engineers. Cooperating in this research was the American Hardboard Association.

Moisture Equilibrium Studies

Wood-base panel materials—such as insulating fiberboards, the medium-density building fiberboards coming into use for siding and similar applications, and particle boards—generally come to equilibrium with atmospheric relative humidity at lower moisture content levels than normal wood, according to early findings of new studies on these materials.

The equilibrium moisture content of these materials must be known so that they can be properly conditioned for use before being installed in a building; otherwise, difficulties can result from shrinking or swelling as the materials come to equilibrium after being installed. Additives put in most wood-base materials to bond them together, exclude moisture, furnish protection from decay, or otherwise improve serviceability often modify their reaction to moisture.

Limited experiments indicate that particle boards come to equilibrium with 30 percent relative humidity at about 6 percent moisture content, as does wood; but at 90 percent relative humidity they attain a moisture content of only about 14½ percent as compared to 21 percent for wood. At intermediate humidity levels,

particle boards attain equilibrium at proportionately lower moisture content levels than does wood.

Typical insulation boards and medium-density building fiberboards also come to equilibrium with a given relative humidity at a lower moisture content than does wood. Generally, their equilibrium moisture content ranges from 50 to 80 percent of the corresponding values for wood at relative humidities between 40 and 90 percent.

Heat Conduction of Materials

As new wood-base building materials are developed, a property of key importance to their acceptance for various uses is their thermal conductivity, or insulating value. Heat conduction varies from high to quite low for the various wood-fiber and wood-particle panel and board materials now manufactured.

Research to establish basic values for typical panel products has yielded an excellent specific gravity—conductivity relationship for fiber-base materials. Values obtained are being submitted for inclusion in the American Society of Heating, Refrigerating, and Air Conditioning Engineers' Guide, now being revised. A similar, though apparently not so exact, relationship between specific gravity and heat conductivity is meanwhile being completed for particle-based materials.

Acoustic Research

The sounds of civilization—traffic, TV and radio, dishwashers, food disposers and other household ma-

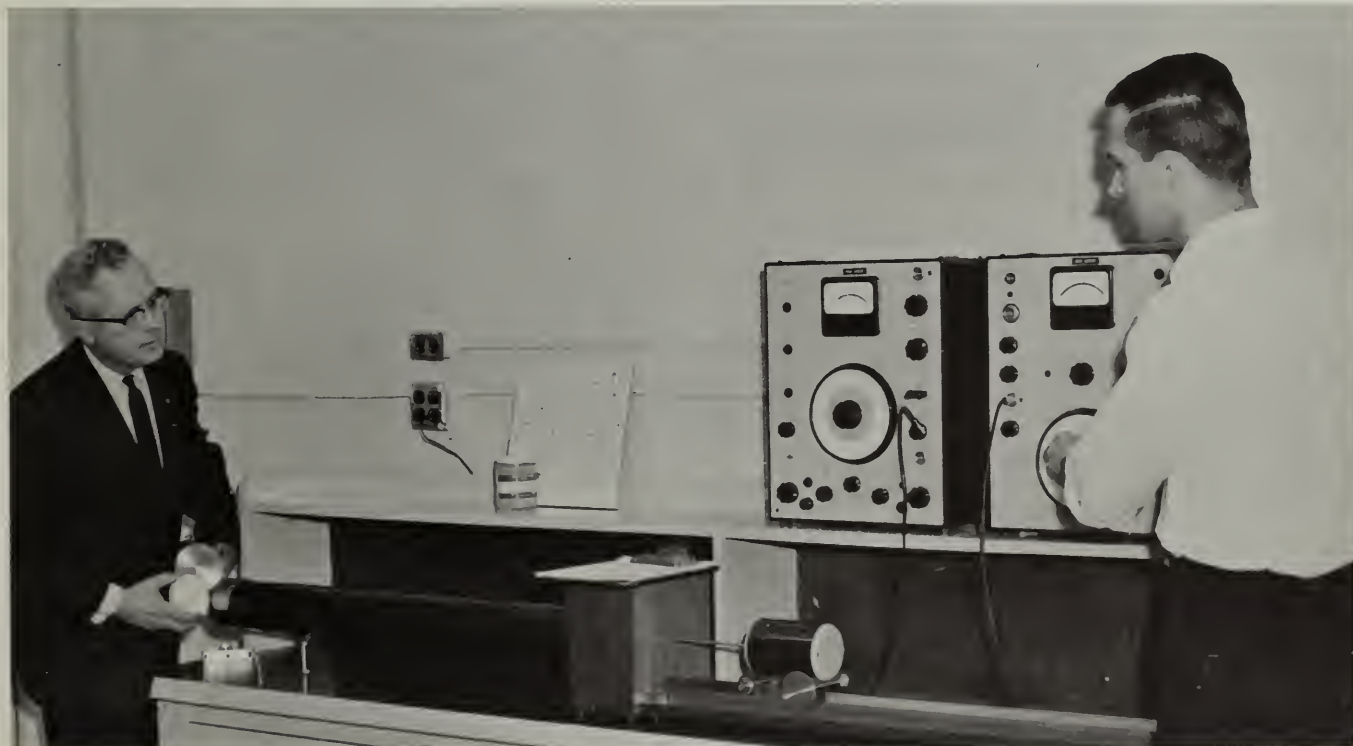
chines, etc.—are bringing demands for better sound proofing in buildings of all categories. Building codes increasingly call for sound conditioning, and home buyers and renters look for it.

To assist industry in obtaining useful information on the acoustical properties of wood and wood-base building materials, FPL is exploring the most promising techniques and procedures for obtaining such data. Basic apparatus is in use for acoustical research and for measuring sound reflectance of different materials. At present, experiments are being limited to evaluations of small specimens through use of impedance tube techniques. Full-scale facilities for room-size wall and floor experiments may later be obtained.

Impedance-tube equipment for measuring sound absorption of materials is being used in exploratory experiments on various materials to gain data for guidance in planning future work. Two materials under study are those being used in a round-robin series of experiments among United States and Canadian laboratories equipped with impedance tubes and full-scale reverberation rooms. Results will provide a firm basis for comparing different types of research equipment and planning further work on typical wood-base materials.

Meanwhile, some exploratory experiments provide interesting findings on the response of different materials to sounds of different pitch (frequency). For example, an FPL-developed pulp-chip particle board (see

Disk of insulating fiberboard is placed in head of impedance tube by Wayne C. Lewis, left, engineer in charge of FPL acoustic research, while electrical engineer James Davis adjusts instrumentation for sound reflectance measurement.



description under Solid Wood Products Research) gave a flat response through much of the audio range, yet reflected enough sound to avoid the dampening effect of a so-called "dead" surface. These results indicate it holds promise for use in concert halls and other places where, though a dead surface is objectionable, some absorption is desired for prevention of echoes.

A Fiber and Particle Panel Products Liaison Committee meets at FPL semiannually to confer with staff members on research findings and programs. Their suggestions as to research needs give practical guidance, and the meetings provide a direct channel for putting research results to industry use. Three organizations are represented on this committee, the American Hardboard Association, the National Particleboard Association, and the Insulation Board Institute.

Hardwood Pallets

An extensive investigation of the suitability of three Appalachian hardwoods, yellow-poplar, red oak, and hickory, for shipping pallets is under way in cooperation with the Forest Service Marketing Research Laboratory at Princeton, Va., which selected the low-grade lumber and logs, and the Carbondale, Ill., Research Center of the North Central Forest Experiment Station.

Five types of pallets, two expendable and three reusable ones, are being compared. Some of the expendable pallets have deck boards of Slicewood, an experimental material produced on the FPL slicer in thicknesses up to $\frac{3}{8}$ inch. Nylon-coated staples were used to fasten the deck boards to the stringers with a semi-automatic stapler that cut assembly time to one-third of that needed for hand-nailing. For the reusable pallets, nominal 1-inch lumber was used as decking.

All pallets were made of green wood, then put in a dry kiln under conditions simulating a heated warehouse. As they dried, the deck boards warped considerably. It was observed that the staples held the deck boards to the stringers better than nails.

One-half of the pallets will be given engineering evaluations to determine which designs and species perform most satisfactorily. These will include rough handling in a large revolving drum and a drop-corner-wise and a bending-stiffness evaluation. The other one-half will be shipped to a fruit processing plant in Illinois for regular use and will be monitored by the Carbondale, Ill., Research Center over a period of time to provide data for comparison of laboratory evaluation and actual service conditions.

Cushioning Design

A new approach to cushioning design, based on the interaction of cushion and container, is being explored. Present knowledge of the protective capabilities of package cushioning is based almost entirely on the response of these materials to dynamic tests. On the other hand, cushioning is used inside a closed container, which has its own individual response to impact loads. The shock force reaching a cushioned item is therefore modified by the container as well as the cushioning.

Containers made of wood or wood-base materials may contribute to shock-dampening properties. Work is therefore proceeding on the shock-absorbing interrelationships of cushioning and containers to find the most efficient designs based on the combined properties of container and cushion. It is believed that packaging costs can thereby be reduced and protection of contents improved.

WOOD QUALITY RESEARCH

Research on computerized techniques is rapidly bringing the dawn of a new era to the woodworking industry when guesswork will be removed from hardwood lumber procurement. In December 1965, a factory trial showed the techniques to be outstandingly accurate in predicting the yield of cuttings of a given size and quality from hard maple and prescribing the most economical standard grade to buy for such cuttings. The trial was the culmination of years of investigation and experiment by FPL and other Forest Service scientists, and by cooperating industries. Potentially the work has great significance for many species and grades of hardwood lumber.

Progress on other phases of FPL wood quality research ranged from highly practical contributions ready for industry adoption to the initiation of new long-term studies on urgent problems. Among these were:

1. Demonstration that heavy losses incurred in the seasoning of thick walnut gunstock blanks with the "wild" grain that produces prized fancy figure in the finished stock can be virtually eliminated by low-cost treatment with polyethylene glycol.
2. Publication of Forest Service research papers that summarize FPL and Experiment Station research findings on the density of standing softwood timber in the South and West.
3. Initiation of an investigation into the causes of mineral or "black" stain in red oak, which annually causes heavy degrade losses of otherwise high-quality lumber for flooring, furniture cuttings, and other high-value products.
4. Completion of a study of the specific gravity of the veneer-yielding portion of southern pine trees, excluding the juvenile core.
5. Launching of research on sawing methods most suitable for cutting lodgepole pine into studs with least degrade from warp.

Hard Maple Cutting Yields

Two experienced sawyers, crosscutting and ripping 1,425 boards of No. 2 Common white maple, made woodworking history one day in December 1965 at a Louisville, Ky., plant. They were producing 1½- by 25¼-inch clear-one-face cuttings for kitchen cutting blocks; but they also were providing evidence that would prove out or reject a new management concept—that a computer can determine the most economical grades, sizes, and quantities of hardwood factory lumber needed to produce cuttings of specified sizes and qualities.

The result was overwhelmingly in favor of the new concept. The number of cuttings produced by the sawyers tallied almost exactly with the prediction turned out earlier by a computer programmed by FPL research workers. The only discrepancy of any conse-

quence resulted from a slight difference in the grade used in the computer calculations—No. 2 Common without qualification for white (sapwood) maple on one face and both edges. The inner heartwood included in the computer calculations necessarily, therefore, contained a few more defects. Allowance for this brought the computer-predicted yield of cuttings in virtually complete agreement with the yield actually attained by the sawyers.



Dr. George Englerth examines wood turning specimens from variously fertilized hardwood trees. His objective is to determine whether growth stimulation with chemical fertilizer adversely affects the machining properties of wood.

M 127 253

The computer program developed for this experiment was the outcome of 5 years of research that began with mill surveys and grade studies by scientists at FPL, the Carbondale, Ill., research center of the North Central Forest Experiment Station, and the Forest Products Marketing Research Laboratory at Princeton, W. Va.

The many variables necessary to consider—character and size of defects, lumber sizes, grade requirements, sizes and quality specifications of cuttings—added greatly to the complexity of the problem. Eventually, however, a computer program was designed that can accommodate up to 100 variations in cutting sizes alone. Besides calculating the most suitable grades and sizes of lumber to purchase for a given set of cuttings, the computer instructs where and how to cut the pieces and whether to rip or crosscut first.

Plans call for extension of the December factory experiment during the coming year to include hard maple of several grades and cuttings of several sizes simultaneously in one computer program. Beyond this, it is planned to extend the research to other species of hardwoods. Close similarity of many standard grades among different species of hardwoods, as promulgated by the National Hardwood Lumber Association, is expected to simplify the necessary preliminary work of analyzing new species and grades for the data needed to formulate computer programs.

Eventually, it is conceivable that lumber buyers will be guided in their purchasing decisions by accurate computer programs specifying the most economical and suitable grades of hardwood lumber for cuttings of any combination of sizes and qualities.

PEG Controls "Wild" Grain

Treatment with polyethylene glycol (PEG) can curb the natural tendency of fancy-grained wood to split and check when its sapwater is removed in seasoning. This finding virtually eliminated the 33 percent loss of 2½-inch-thick fancy gunstock blanks that had handicapped production at one mill and cutting blanks from knotty, crooked black walnut logs.

The scarcity and high cost of black walnut make the treatment especially valuable for this species; fancy blanks bring \$12 apiece from gunstock manufacturers. It is estimated that about 10 percent of the 2,500,000 walnut blanks produced annually are fancy-grained; because of seasoning losses and heavy demand from gun fanciers, these blanks bring premium prices. By preventing seasoning losses with PEG treatment, the industry conceivably could save upwards of \$800,000 and use some 300,000 board feet of high-value, critically short walnut lumber now scrapped.

The treatment is simple. It consists of soaking the green, fresh-sawn blanks in a 50 percent (by weight) water solution of PEG-1000 just before they go into the kiln. A 10-day treatment in a solution kept at 140° F.



Evolution of a three-ply fancy-grained laminated walnut gunstock. Left to right, original thin laminations as sawn from wild-grained cull log ready for treatment with polyethylene glycol to improve dimensional stability and prevent drying damage; blank of three laminations glued together; a machined stock ready for mounting; a completely finished stock, showing handsome grain pattern, fitted to rifle.

M 130 616

will suffice, experiments have shown. Cost of heat and chemical is estimated at about 20 cents per blank.

The treatment is also of value for salvaging usable wood in thin, odd-shaped slabs and other short material left over from squaring up logs and cutting them into thick blanks. This thin fancy-grained material is like-

Crooked, knotty walnut logs to be sawn into "wild-grained" gunstock blanks are examined by sawmilling specialist Hiram Hallock and Harold L. Mitchell, chief of wood quality research.

M 130 002



wise difficult to season—and PEG treatment eliminates the seasoning damage hazard and also provides a high level of dimensional stability. It can be cut to gun-stock pattern shapes, heavily treated with PEG, and then glue-laminated to any desired thickness. In a three-ply blank, only the outer laminations need be of fancy-figured material. Stocks made from stabilized laminated blanks are warp proof, structurally superior, and just as attractive as solid wood stocks.

Southern Pine Density Research

A milestone in the survey of southern pine standing timber to establish significant statistical data on its specific gravity as an index of quality was reached in 1965 with the publication of a status report. Progress in the survey work has been covered in previous FPL annual reports. The status report was jointly issued by FPL and the Southern and Southeastern Forest Experiment Stations.

Together with a similar one of 11 Western States and another of Maine softwoods, this survey was the first ever undertaken anywhere nationwide for mass evaluation of standing timber quality as related to soil, species, growing conditions, and other factors. Four species, longleaf, shortleaf, loblolly, and slash pine, were systematically sampled by field crews of the Stations and FPL in the States of Alabama, Arkansas, Florida, Georgia, Louisiana, North Carolina, and Mississippi.

Specific gravity is primarily an index of strength and stiffness, hence of direct value to lumber and plywood producers. It is also, however, a recognized index of pulp fiber content and hence a guide to pulpwood producers and buyers. Moreover, data on the relationship of soil, growth conditions, and other factors associated with specific gravity offer basic guidance in the management of timber.

The status report is primarily a statistical analysis of the specific gravity measurements of increment cores bored from trees at breast height. For each species, it presents simple regression equations for converting core specific gravity to a weighted average for the whole tree by diameter classes, for all diameters, and for sawtimber material in trees 9 inches and up in diameter.

For lumber and pulpwood, the entire log or bolt is used. When rotary cutting veneer for plywood, however, an inner core is discarded. This inner core usually contains so-called "juvenile" wood, which is lightweight and weak. In the smaller trees, this often is enough to significantly lower the average specific gravity value for the entire tree.

Accordingly, for the guidance of the burgeoning young southern pine plywood industry, specific gravity data were re-evaluated, omitting the core of juvenile wood, and preliminary regression equations were developed in which correlation coefficients specifically account for the veneer portion of the log. To do this, it was necessary to destructively sample a representative

number of trees. Disks were sawn from the ends of veneer bolts cut from the trees and quartered; specific gravity data were then obtained from various segments cut radially from two of the quarters. Thereby the specific gravity of the core wood was established separately from that of the outer wood exclusively used for veneer. The average specific gravity of the veneer-potential wood in each bolt could thus be calculated. Regression analysis was employed to find the relationship between the specific gravity of the veneer-potential portion of the merchantable boles of trees and that of the increment cores taken at breast height in the standing trees.

The sampling of trees to establish this relationship was done in Texas, where 158 loblolly and 79 shortleaf pines were felled. Only limited check samplings will probably be necessary to extend this relationship to core gravity data obtained on these species in other southern States.

Western Wood Density Research

Also published in 1965 was Report No. 1 of the Western Wood Density Survey as a joint report of FPL and the Pacific Northwest, Pacific Southwest, and Rocky Mountain Forest and Range Experiment Stations. Review copies of this report had been issued in 1964 to interested government and industry agencies, and its substance was summarized in the 1964 Annual Report.

The geographic rainfall patterns and associated factors that had been found to exert a controlling influence on specific gravity of southern pines did not similarly appear in the density survey data on western woods. This was especially true for Douglas-fir, despite its broad habitat range throughout the West from Washington to New Mexico. Considerable variation was found even within localized areas, the causes of which were not readily apparent from the core density data.

A new study was therefore begun during 1965 which was designed to take into consideration two basic factors, summer rainfall and elevation. Both significantly affect wood formation in the tree. From U. S. Department of Commerce Weather Bureau records, 45 locations were pin-pointed on the west slope of the Cascade Range where one of 15 combinations of elevation—summer precipitation occurred. Precipitation ranged from 3 to 27 inches and elevation from 300 to 2,475 feet above sea level.

On these sites, 225 Douglas-firs were tapped for increment cores; all were dominants past the age of juvenility. Vegetation and soil were also sampled at each site. The parts of the cores consisting of wood produced during the period covered by the Weather Bureau records are being measured for tracheid size and specific gravity of the springwood, summerwood, and entire ring. How these data relate to elevation and summer precipitation is being statistically analyzed.

Walnut Growth—Properties Study

Clear-cut evidence that fertilization can speed the

growth of at least some hardwood species without impairing wood properties for high-value uses such as furniture and paneling encouraged the launching of such an experiment during 1965 on a natural stand of that most valued of native American hardwoods, black walnut.

The evidence had been obtained from red oak, yellow-poplar, and white ash trees fertilized in 1935 with nitrogen. When bolts from some of these trees reached FPL 25 years later, growth was found to have been stimulated up to three-fold, as indicated by width of annual rings. Furthermore, the stimulation continued for up to 8 years. Nevertheless, there was no impairment of machinability and toughness, key properties for woodworking.

In recent years, black walnut has risen spectacularly in price. Demand has created shortages and the threat of increased scarcity. An extensive research study of all factors involved in walnut breeding and culture, including fertility of soil, is under way by the North Central Forest Experiment Station; FPL is cooperating in its wood quality aspects.

To gain data on the wood-quality effects of fertilization of larger timber than included in the Station program, FPL scientists initiated another study in 1965 on a typical stand of mixed hardwoods in southwestern

Shotgun pellets rip twig from walnut tree for analysis of leaves for nitrogen fertilizer content.

Wisconsin. Twenty walnut trees of small sawlog size were fertilized with nitrogen on a lowland site and 20 others on an upland site. Analysis of leaves in late summer showed a substantial increase in nitrogen content of those taken from fertilized trees.

Observations and measurements will be made yearly on these trees, together with equal numbers of unfertilized trees of matching size on both sides. In about 5 years, sample trees will be cut and their wood given veneering, machining, and toughness evaluations.

Black Stain in Red Oak

A costly discoloration in red oak, called black stain, in 1965 drew the attention of FPL scientists as producers of flooring, furniture dimension stock, veneer, and other hardwood products reported heavy and increasing losses due to its downgrading presence in otherwise high-quality timber. The National Oak Flooring Manufacturers Association, after surveying production at 38 mills, reported that as much as 25 percent of all No. 1 Common lumber was reduced to that grade because discolored by the stain, along with 33 percent of all No. 2 Common. The stain made it unacceptable for such high-value products as flooring and exposed furniture parts. At prevailing production rates, flooring industry losses alone were estimated to be \$100,000 a week. There is also a strong tendency for the stained wood to honeycomb during drying.

Cause of the stain is unknown, and one object of the research is to identify it. FPL pathologists, chemists, and technologists began a concentrated study of the stain that included visits to growing sites and producing mills in a number of States of the Appalachian region. Timber owners and mill operators were consulted, and samples of discolored wood were brought back to FPL for laboratory study.

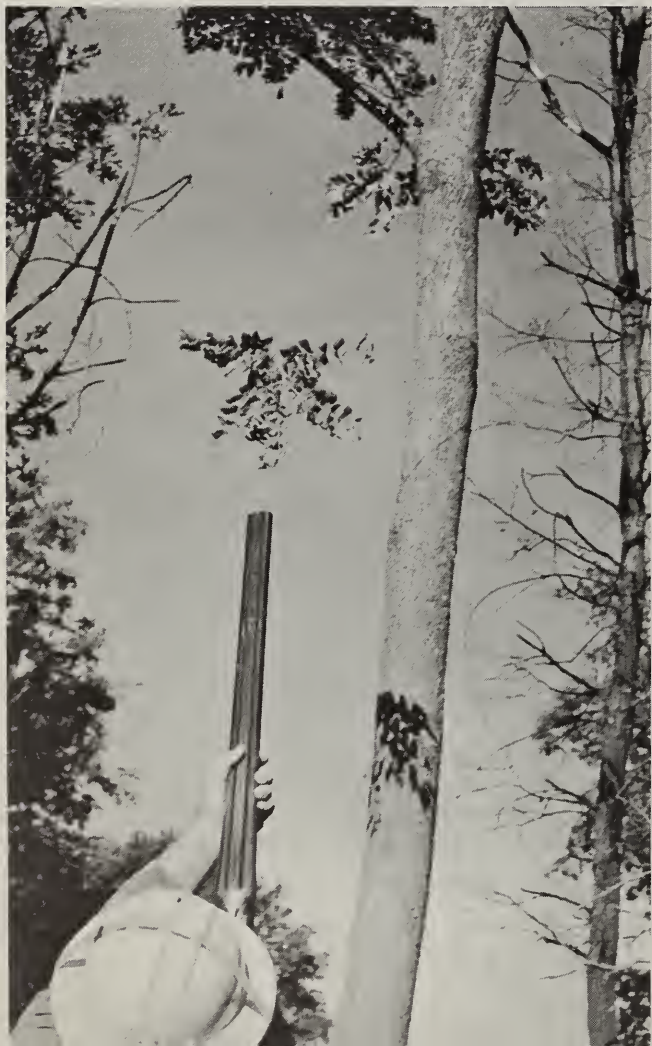
Study material was also obtained from trees being felled by crews of the North Central Forest Experiment Station during the summer for other research purposes.

Anatomical and chemical studies of the stained xylem indicate that its formation may be the result of abnormal physiological disruptions during the transition from sapwood to heartwood. Examination under the electron microscope revealed dark amorphous deposits in the lumen and pits of parenchyma and tracheid cells. These deposits are quite complex chemically, and their properties suggest that they are polymeric oxidized materials of high molecular weight. A number of bacteria and fungi have been isolated from trees containing the stain, but the role of these organisms as causative agents remains to be established.

Work is being continued with funds provided under the Appalachia Regional Development Act of 1965.

Lodgepole Pine Stud Warp Control

The successful control of warp in loblolly pine studs that resulted from modified sawmilling techniques (see 1964 Annual Report) prompted a decision to apply simi-





Technologists Erwin H. Bulgrin, left, and James Ward examine cross section of a red oak tree discolored with black stain.
M 129 252

lar techniques to lodgepole pine, the major small log species in the Rocky Mountains.

A pilot run, made with the two most common sawing techniques employed by industry, was used on 210 logs to get data on warp, occurrence of compression wood (a major cause of warp), differences between butt and upper logs, and log diameter. These data will be used to determine the sample size for a full-scale, statistically designed sawmilling study.

Preliminary results from this pilot run indicate that when the studs have been dried to an average moisture content of 12 percent, bow and crook are at least as prevalent as in loblolly pine and the incidence of twist appears to be higher. There was less visibly evident compression wood than in loblolly pine, but the lodgepole pine logs were more eccentric.

As an analysis of the data gathered on loblolly pine showed, longitudinal growth stresses are responsible

for crook or bow in a piece of lumber while being sawn or immediately after it is sawn. The strain in the lumber and the log is responsible for the well-known condition of "spring" or "timber bind" that causes sawyers never-ending trouble.

The magnitude of the growth stresses in the loblolly pine was determined mathematically from a relationship of the green bow in the piece of lumber, its length, thickness, modulus of elasticity when dry, and moisture content. The direction of the green bow relative to the pith indicates whether the stud has a tension or a compression stress gradient. The growth stresses may be such that the resulting stresses in the tree have a gradient from compression in the central portion to tension at the outside, or vice versa. Pieces cut from a log with tension on the outside are said to have a "tension gradient" so that, immediately when cut, they bow away from the outside of the tree. For

the reverse condition, they are said to have a "compression gradient" and bow away from the pith.

About a third of the loblolly pine studs cut from the central portion of the log showed a compression gradient. At a distance radially about 4.5 inches from the pith, however, five times as many studs showed tension stress gradients as compression gradients. The incidence of compression stress gradients is significantly higher in logs with visibly evident compression wood, which shrinks longitudinally much more than does normal wood.

The longitudinal growth stress was found to range from 0 to 1,500 pounds per square inch, with a mean of 139 pounds. This value, though small in comparison with hardwoods, is enough to make an 8-foot stud bow 3/32 to 7/32 inch at midspan, depending on the stud's modulus of elasticity. Deflection resulting from growth stress release was as great as 1-11/16 inches.

Theoretically, studs showing tension stress gradients should tend to reflect a normal wood condition and low warp potential. Those showing compression stress gradients should reflect presence of compression wood and high warp potential. The degree of deflection in green studs with a compression gradient, moreover, should be an indication of the intensity of the compression wood. Very little statistical evidence was obtained, however, from analysis of data on warp in green and dry studs to indicate that this may be so.

16

Latin American Woods Evaluation

A greatly broadened program for evaluating the timber resources of five South American Nations was conceived during 1965 in cooperation with the Agency for International Development. The project has developed from a study of Peruvian woods under way for several years, which is providing a wealth of practical and academic information. With AID funds, Venezuela, Colombia, Ecuador, and Amazonian Brazil are to be included.

Forestry agencies of the South American lands will collect and send wood specimens of adequate size to FPL for evaluation of basic mechanical and physical properties. It is expected thus to obtain invaluable data on approximately 800 to 1,000 tree species for future development of timber industries. In addition, herbarium specimens (leaves, flowers, and fruit) will be obtained for identification purposes. If experience with Peruvian Forest Service officials is any guide, the project should also provide excellent training of field workers in techniques essential for accurate forest inventory and survey.

Other research and identification service work involving Latin American woods included an investigation of the occurrence of microscopically visible silica in trees of the family Lauraceae. Several interesting species were uncovered in this work. Two specimens were apparently of the same species as yet unnamed; these may prove to be a new genera. Another specimen, *Ocotea glaucina*, was found to be unique among

the American Lauraceae in that silica occurs only in the septate fibers—fibers with cavities compartmentalized by internal cross walls. Study indicates that such crystalline inclusions may make it possible to distinguish genera from one another—something not heretofore possible from the wood alone.

Taxonomists are showing increasing interest in the use of wood anatomy as an adjunct to classification. For example, a tree species collected in Costa Rica was recently proposed as a new genus and species of the family Flacourtiaceae. Examinations of the wood at FPL, however, showed that it belonged to the family Elaeocarpaceae, which is Australian in origin, specifically to the genus *Elaeocarpus*. The taxonomist submitting the specimen then found that the tree was indeed an Australian introduction which had become naturalized in Costa Rica and had been known since the time of Linnaeus as *Elaeocarpus serratus*.

Wood Identification Service

The free wood identification service that FPL operates in connection with its research on the physical structure of wood brought requests for such service from a broad spectrum of governmental and private agencies during 1965.

A decided increase was noted in requests from museums and related institutions. The increase stems apparently from archeological explorations in the Near East—notably, underwater archeology in the Mediterranean Sea. Specimens of wood taken from sunken Greek and Roman ships were identified as pine and elm from planking and decking and oak from the treenails used to fasten parts together.

Dr. B. F. Kukachka unpacks primitive African wood carvings sent him by museum for identification.
M 129 874



Specimens of furniture artifacts found by archeologists in Iran and dated about 1,000 to 800 B. C. were identified as yew, cypress, juniper, tamarisk, boxwood, and jujube. Oddly enough, the highly publicized cedar of Lebanon is rarely encountered in these ancient artifacts.

While the total number of requests for identification was up somewhat in 1965 from the preceding year, the number of specimens received was substantially greater, so that the work load remained high. Requests numbered 876, as against 860 in 1964; specimens identified totaled 3,013, as compared with 2,946 the previous year.

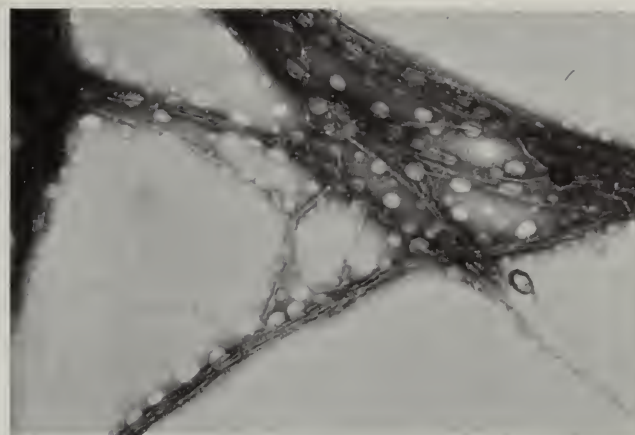
Submicroscopic Structure of Wood

Cellulose morphology is under study by Dr. John D. Sullivan, Assistant Professor of Wood Science at Duke University School of Forestry, while on a 14-month sabbatical leave at FPL. Electron micrographs of individual cellulose molecules, called "elementary fibrils," have been obtained for both softwood and hardwood species.

The generally accepted theory of cellulose morphology recognizes two distinct orientations of the elementary fibrils, parallel orientation in crystalline areas

Dr. John D. Sullivan, Duke University professor on sabbatical leave, photographs cellulose microfibrils with FPL electron microscope.

M 130627



Cellulose microfibrils of longleaf pine, 35 Angstroms in diameter, appear in electron micrograph as fine white, threadlike structures interwoven in fiber wall. Magnification 74,000 diameters.

M 130 640

and random disposition in amorphous regions. Recent research findings have led Dr. Sullivan and others to believe that such a structure does not exist but rather that the molecule is in the shape of a helically wound ribbon. The diameter of the molecule is an important aspect of the new theory, and the present research is directed toward the clarification of this point.

Results to date indicate that elementary fibril diameter varies as a function of the cellulose source, delignification forces, and drying stresses. Measurements have varied from as low as 10 Angstroms to as high as 50 Angstroms. Preliminary results also indicate that single elementary fibrils are fasciculated with one or more other elementary fibrils, forming small bundles more or less periodically along the length.

Dr. Sullivan will continue the studies with unique electron microscope techniques as well as with low-angle X-ray diffraction and possibly with micro-infrared spectrometry.



SOLID WOOD PRODUCTS RESEARCH

The many processes involved in putting wood to use in its natural form—among them drying, cutting, gluing, painting, and protective treatments for decay, insects, and fire—constitute the work of the Division of Solid Wood Products Research. Inherent in this assignment are both basic and applied research, as well as the origination and development of new and improved processes and products.

Highlights of 1965 that exemplify this research included:

1. Development of a distinctive paneling and flooring from low-quality red oak logs by a process featuring high-temperature press drying.
2. A basic finding that fire progresses in large enclosed areas by sudden leaps called flashovers as hot combustible gases seek fresh oxygen, and that these flashovers occur predictably regardless of whether walls are combustible or non-combustible.
3. Discovery that a new technique called immunofluorescence makes it possible to observe with the microscope how the tiny, hairlike hyphae of decay fungi penetrate the cell walls of wood, thus yielding new basic information on these destructive saprophytes.
4. Field trials in Mississippi of a termite bait containing both an attractant and an insecticide, which showed that the bait apparently discourages these wood-destroying insects from infesting areas where the bait was experimentally tried.
5. A thick, low-density particle board with excellent stiffness and satisfactory strength and dimensional stability for roof decking, yet economically made of pulping-size chips and thin flakes held with relatively little bonding resin.
6. A method of predicting the long-term durability of adhesive joints in plywood by accelerated aging.

Paneling, Flooring of Low-Grade Oak

From low-grade red oak logs customarily used only for such things as pallet stock, dunnage, and railroad ties, lumber for paneling and parquet flooring was produced that has a distinctive color and a reduced tendency to swell and shrink. Both the color and the dimensional stability are acquired by drying the wood in a hot press. Sound knots, mineral streak, and other characteristics that normally lower the grade of lumber are acceptable and desirable in the paneling but removed from the flooring.

The singular color, resembling chestnut or walnut rather than the pinkish hues of red oak, is ascribed to the effects of heat on the tannins and other extractives in the wood. Dimensional stability is obtained because the green wood is restrained from shrinking while the

bulk of its moisture is removed.

Logs were sawn into wane-edged boards 5/8 inch thick. These went directly to the hot press. In an hour they were dried sufficiently for use as indoor paneling and flooring, furniture stock, and other products. With appropriate schedules, it is possible to kiln dry such material in less than 2 days.

The dried boards were surfaced to final 7/16-inch thickness and then marked for cutting into panel and flooring stock. Panel cuttings were full 2-, 3-, 4-, and 6-inch face widths and lengths up to 8 feet in 16-inch increments. The pieces were then sawn from the boards and tongued and grooved along all four edges. The reason for using full-inch widths rather than the conventional nominal lumber sizes was to facilitate use of different widths randomly in a single course of paneling. Thus, a 2-inch and a 4-inch piece, three 2-inch pieces, or two 3-inch pieces could be used next to a single 6-inch piece in the same course. Pieces were tongued and grooved at the ends so that they could be joined together anywhere between studs. Nailing of ends to studs or joists is avoided because the thin, dense oak may split.

Pieces for flooring blocks are 9 inches long and grooved along the ends. A 1/8-inch veneer spline is glued in each groove to hold the pieces of the block firmly together and project about 1/4 inch. The other two edges of the block are then grooved. Blocks are laid in mastic or blind nailed to a subfloor at right angles to each other, so that veneer splines of each block fit into grooves of adjoining blocks.

The 12 logs used in this study would have produced about \$28 worth of railroad ties and lumber. The retail value of prefinished paneling at 50 cents a square foot (the price of a similar product) would be about \$280. Estimating the value to the producer at one-half the retail value (\$140), would mean a five-fold increase in the contribution to the local economy over producing ties and lumber.

The paneling and flooring were developed in research supported with funds of the Appalachian Regional Development Act of 1965. A detailed report on the findings was sent to the Forest Products Marketing Laboratory maintained at Princeton, W. Va., by the Northeastern Forest Experiment Station. Economic feasibility of the process is being studied here.

Press drying was first tried at FPL some 15 years ago with 1/8- and 1/10-inch veneers, which were then bonded to concrete subfloors of laboratory offices. Excellent service has been obtained from these floors, which resemble conventional strip flooring.

Research is continuing on press drying of oak, hickory, aspen, and other species in thicknesses up to 1 inch. At a press temperature of 350° F., drying rates and

temperature changes in the wood are being studied. Among significant findings are:

1. Rate of drying is a direct function of the heat applied to the board surface.

2. There is some hope that moisture can be rapidly removed without seriously degrading either the surface or interior of the piece.

3. Extreme temperature and moisture gradients and the platen pressure are believed mainly responsible for the marked reduction in width shrinkage that takes place.

4. Plasticizing effects of heat on wood may be the reason why rapid press drying causes little degrade.

5. Less final surfacing is necessary than with conventionally dried wood.

6. Besides shrinking less in width, the wood is less hygroscopic when press dried.

The potential of press drying is believed to be great. We estimate that it could be used to dry 50 percent of all hardwood lumber and 10 percent of softwoods. If savings in drying costs and wood quality over kiln drying were \$2 per 1,000 board feet, at current annual rates of production this would add up to \$6 million a year for softwoods and \$7 million for hardwoods.

New Particle Board Products

Promising results were obtained in experiments with two types of particle boards, one a three-layer construction for roof decking, and the other a single-layer chipboard for ceiling panels.

The roof decking is approximately three times as stiff as conventional fiberboard decking. It has also been found satisfactory with respect to thickness swell, linear movement, strength after exposure to a six-cycle aging test, and creep (distortion) under sustained load of 150 pounds per square foot.

Common pulp chips comprise the thick core, which is faced with thin wood flakes on both sides. About 5½ percent of the weight consists of the phenolic resin used to bind the chips and flakes together. The chips can include knots, some bark, and defective wood without seriously impairing board strength. Experiments to date have been mainly with aspen, a lightweight hardwood plentiful in the East, Lake States, and Rocky Mountains. Western redcedar and redwood were also tried. Results indicate that any low-density, fast-growing species can be used.

Installing experimental ceiling tile made of pulp chips.

M 128 782



The ceiling panel board, ¾ inch thick, is being tried as a lay-in type of ceiling in an FPL office. The 2- by 4-foot panels have a rough surface created by the random alinement of the pulp chips. This surface contributes some sound absorption with a unique flat response regardless of the frequency of the sound waves—differing in this respect from many conventional sound-insulating materials, which absorb the higher frequencies more effectively than low frequencies.

Highway Bridge Research

In several related studies, FPL scientists investigated various aspects of the serviceability of timber bridges. One study was concerned with the long-time performance of laminated bridge timbers treated with various preservatives, another with a new type of laminated bridge decking; a third with the development of decay in bridges; and a fourth with a method of fortifying timber joints in bridges with special preservative treatments.

In the study of laminated bridge timber performance, 12 bridges used for periods up to 20 years in 5 States were investigated. Oil-borne preservatives such as creosote, creosote-oil mixtures, and pentachlorophenol in heavy oil were found to be more effective than water-borne preservatives in preventing surface checking and delamination of the glue bonds. Coatings formed by exuded oil-borne preservatives apparently retard moisture changes enough to reduce shrinking and swelling and accompanying checking significantly, as well as delamination. No decay was observed on external faces of timbers treated with either oil-borne or water-borne preservatives.

Studies of Forest Service road bridges in several western and southern States revealed that rain seeping between deck planks onto supporting timbers is the most frequent cause of decay. Wood at the tops of stringers and piling is thereby kept wet enough to permit growth of fungi. Decks of the western bridges are usually made by nailing planks together face to face as they are installed on edge on the supporting timbers. This finding has led to several experiments now under way to fortify these bridges against such decay.

On one bridge, half of the deck has been covered with a weather-resistant and flexible asphaltic coating to seal out rain water. The same thing will be done on one other bridge. From time to time, the moisture content of the stringers will be measured with moisture-sensing electrodes permanently installed at several critical points in each bridge.

In another experiment, pads saturated with preservatives are inserted in critical joints between untreated wood members simulating those of bridges. These are being exposed to the weather for extended periods of time to evaluate the effectiveness of the pads in preventing decay. Such pads could also be used to protect treated timbers at points where the treated



Pads saturated with wood preservative are being experimented with as protection for various types of joints used in wood bridges. Here Technologist Lee Gjovik examines one type of joint. M 130 228

20

outer layers of wood have been cut away at joints, or between wood members and masonry foundations.

Still another approach to the prevention of rain seepage through bridge decks is an experimental glued-laminated bridge decking also being evaluated under outdoor service conditions. Both preservative-treated and untreated decking, glued with a waterproof phenol-resorcinol resin, is being tried. Some deck sections are also covered with wearing surfaces of experimental asphaltic compounds. The first 6-month inspection gave encouraging results.

Contamination of Creosote in Piling

Marine piling used in bridges, docks, and other harbor installations usually is heavily treated with creosote to prevent attacks by destructive sea organisms such as teredos and limnoria. In a cooperative study with the Department of the Navy and the American Wood Preservers' Institute, FPL scientists investigated creosoted piling in the harbor of San Juan, Puerto Rico, that had been attacked by limnoria. Creosote extracted from the wood in the extreme outer layer of the intertidal zone appeared to be contaminated with petroleum oil. Fuel oil floating on the water in that part of the harbor was believed responsible.

In experiments designed to prevent such dilution of the preservative, test pilings with the intertidal zone protected with metallic shields and plastic coatings have been driven in the harbor. Other experimental piles were first treated with a water-borne copper-chromium-arsenic combination, kiln dried, and then treated with creosote. The water-borne preservative

is expected to protect against limnoria and the creosote against teredos.

How Fungi Attack Wood

Some of the mystery surrounding the process whereby decay fungi destroy wood was removed by an FPL pathologist, Dr. Catherine Duncan, while on a special Forest Service research assignment and a National Science Foundation research fellowship at the Swiss Institute for General Botany in Zurich for 18 months during 1963-65.

Dr. Duncan had gone there to develop a technique involving immunofluorescence, by which she hoped to observe living hyphae at work on wood under the microscope. Observations would, she anticipated, help clarify certain problems as to how the hyphae decay wood. Such observations have hitherto been impossible because methods often used for preparing specimens of decayed wood for microscopic study necessarily killed the fungi. The immunofluorescence technique, previously developed by bacteriologists for study of human diseases, appeared to give promise of permitting study of living hyphae in wood.

The technique consists of injecting a specific fungal enzyme or protein into the blood of a rabbit, where it acts as an antigen and stimulates production of an antibody. When this antibody is coupled with a fluorescent dye, it can be seen under the microscope with fluorescent illumination, glowing yellow-green when it unites with the specific fungus or enzyme used to produce it. Thereby a specific hypha or an enzyme can be plainly seen in the wood. Thus the way was opened for gaining new knowledge of the mechanisms involved in fungal deterioration of wood. Among findings, Dr. Duncan lists:

1. The cellulase enzyme is not necessarily located at the tip of a hypha, as previously hypothesized, but may be distributed for a considerable distance back from the tip.
2. The cellulase enzyme apparently does not migrate to any great distance from the hypha that discharges it. This indicates that close contact between the hypha and the cell wall may be necessary for attack on the cellulose.
3. Mechanical force does not appear to be needed for hyphal penetration through a cell wall. Cellulase is produced conspicuously at the zone of penetration and could degrade the cell wall to permit passage of hyphae through it.

Mold, Bacteria Aid Liquid Movement

Research was resumed on the possible utility of a previously discovered action by certain molds, notably *Trichoderma* spp., in destroying the wood ray cells to improve absorption of liquids into wood. Controlled use of this phenomenon may prove beneficial in treatment of species that are difficult to penetrate with preservatives.

Certain bacteria can also promote the passage of liquids through wood by dissolving the membranes in



Corridor in which flamespread experiments were conducted at former Waukesha, Wis., School for Boys. Workman readies wood crib for ignition. Walls were lined with oak flooring for this, the third in series of fire progression experiments.

Flashover of hot combustible gases was main cause of flame spread in corridor burnout experiments.

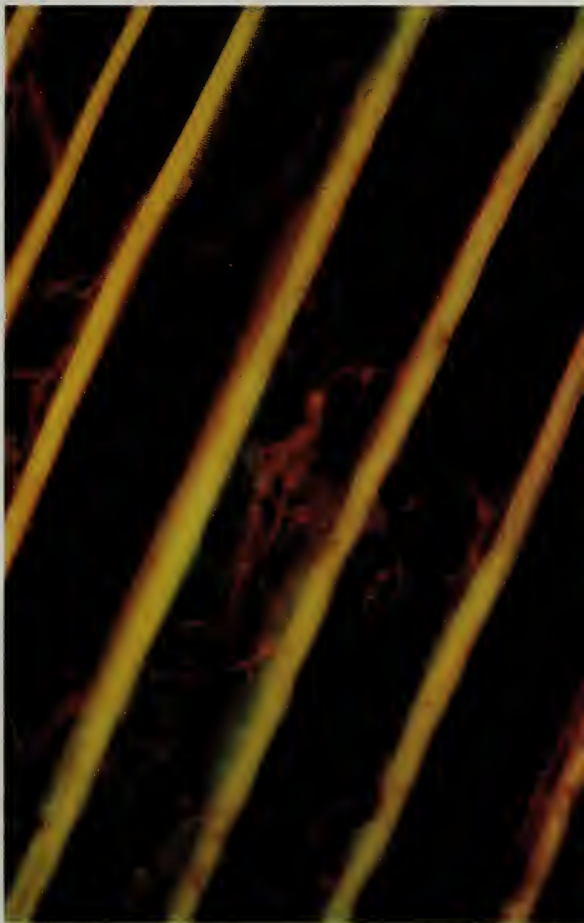


Rich color tones of press-dried red wood demonstrated by FPL Secretaries Gloria Baker, June 1964.



Flooring, wall paneling are admired
in loge.

Fungus hyphae appear under microscope
as red tentacles in decayed
wood stained by fluorochrome dye.



Flashover of hot combustible gases was main cause of flame spread in corridor burnout experiments.



Rich color tones of press-dried red oak flooring, wall paneling are admired by FPL Secretaries Gloria Baker, Judy Broge.

Fungus hyphae appear under microscope as red tentacles in decayed wood stained by flouarochrome dye.





Crooked, knotty logs are inspected by Bruce Heebink, FPL research engineer, before being sawed for paneling and flooring.

M 124 897

the pits as well as ray cells. This was found to be especially true in southern pine veneer cut from a log that had been stored for some time. Removal of ray parenchyma, which extend horizontally in the tree in the bark-to-pith direction, was obvious under the microscope. Besides facilitating treatment with preservatives and other chemicals, and removal of moisture, the bacterial action was found to reduce the force against the roller bar required to cut the veneer from the log. Toughness and flexural characteristics of the veneer apparently were not seriously impaired. These findings may prove of significant value to the new southern pine plywood industry, since bacterial action can occur in logs stored for even a short time.

Mississippi Trials of Termite Bait

Evidence that a new termite bait containing a lethal

Termites thrive under ideal conditions in this chamber closely controlled for temperature and humidity, as Dr. Glenn Esenther, entomologist, studies their living habits. M 130 227



insecticide and a recently discovered attractant may prove to be an effective weapon against these highly destructive insects was obtained in field tests in Mississippi, where heavy infestations exist, during the summer of 1965.

Earlier research had shown that the attractant lures termites. It is an, as yet, unidentified component of decayed wood.

The Mississippi trials demonstrated that the lure is effective even when associated with a feeding material such as fiberboard, containing insecticide. The termites feed on the bait and were not seen in the immediate area again, even on untreated wood. The results were not so conclusive as had been hoped for, however, since it could not be established whether they returned to their nests and were killed, or simply went elsewhere to forage. The fact they did not return is regarded as a favorable indication that the attractant-insecticide may prove effective protection for wood structures without extensive use of soil poisons or other insecticides.

One unfavorable development was the formation of mold on the bait. This appeared to counteract the attractant, rendering the bait useless. Possibilities of preventing mold formation are being studied.

Fire Research in Abandoned Building

A rare opportunity for full-scale fire research in an abandoned building yielded significant findings as to how fire progresses in large enclosed areas. Especially noteworthy was the observation that fire progresses by sudden leaps called flashovers as it exhausts oxygen in one area and flames again as hot combustible gases reach a new source of oxygen, rather than by steady progression as it consumes combustibles on floors, walls and ceilings. Flashover occurs regardless of the combustibility of the wall lining materials. This finding may hence have a strong bearing on the acceptability of wood and other combustible paneling and floorings, if borne out by further research.

The experiments were conducted in a corridor of a former correctional school for boys at Waukesha, Wis. The city had purchased the land from the State, and was about to remove the buildings. With the cooperation of city and State officials, the fire experiments were arranged.

The corridor chosen was 72 feet long, 11 feet wide, and 13 feet high, with a door at one end, two windows at the other, and doorways in each wall near midpoint. Walls were of brick, to which wood furring strips had been attached for application of wood lath and plaster. A pine wainscot covered the walls to the 3½-foot height. The ceiling was also plastered wood lath nailed to upper-story wood beams.

The first experiment was conducted in the corridor as built, with the walls and ceiling essentially noncombustible except for paint and the wainscoting. For a second experiment, the walls were covered with a prefinished, ¼-inch-thick hardboard furnished by the

American Hardboard Association; and for the third they were covered with 25/32-inch-thick oak flooring. The flooring was selected as a "control," since oak lumber is the standard used in the tunnel furnace tests for judging rate of flame spread on different materials. It was hoped that some correlation with tunnel flame-spread data might be gained in the corridor experiments.

In each experiment, however, fire was found to progress by flashover before flame spread could become substantial along the walls.

Flashover is a phenomenon noted by previous experimenters in fire research. It has generally been attributed, however, to spontaneous ignition of combustibles with rising temperature at different points in a room. The corridor experiments indicate strongly that the movement of hot gases from the immediate vicinity of the original flaming to a source of fresh oxygen is the more likely cause. Flashover may even be repeated several times in a large enclosure as air infiltrates the room after each flashover, followed by vigorous burning and then depletion of oxygen.

In all three experiments, flashover occurred within 6 or 7 minutes after ignition of the standard wood cribs used, which were designed to produce ceiling temperatures closely in accord with those prescribed in procedures of the American Society for Testing and Materials. In the first experiment, wainscoting near the cribs ignited in about 4 minutes and paint on the plaster walls $\frac{1}{2}$ minute later. The hardboard paneling did not ignite before the first flashover occurred. The oak flooring was flaming to a distance of about 25 feet along a wall near the ceiling when the first flashover occurred.

Data on temperatures and on the development of smoke, carbon monoxide, and other gases were also obtained.

Rotary Cutting of Veneer

Experiments in the cutting of veneer on the rotary lathe with a roller pressure bar showed that quality of veneer can be considerably improved by adjustment of the roller bar settings. A vertical opening of 1/16 inch above the knife edge was found to be suitable for both southern pine and yellow-poplar veneers 0.094 and 0.364 inch thick, and presumably for any lesser or in-between thickness. The best horizontal roller bar opening, however, depended on the species, log quality, and veneer thickness. At a given setting, yellow-poplar veneer was generally superior in smoothness and tension perpendicular to grain to the southern pine. Breaks ahead of the knife tip were prevented in 0.364-inch yellow-poplar veneer when the roller bar opening was 0.060 inch less than the feed.

Continuous Application of Overlays

A roller press was installed and experiments begun on the continuous application of overlays to plywood and lumber. Overlays of resin-treated paper and vulcanized fiber have shown great promise for concealing



Experimental roll laminating press applies sheet of polyvinyl fluoride film coated with a special adhesive to plywood similarly spray-coated while Technologist Chester G. Roessler, in background, examines a freshly bonded specimen. Process is being studied for fast continuous bonding of overlay materials.

M 130 345

defects in low-grade lumber and providing an excellent paint base. One major drawback to their use, however, has been the cost of application. Continuous application with roller pressure is perhaps the most promising method from a cost standpoint.

In the current experiments, overlays of cellulosic materials and plastic films such as polyvinyl fluoride, polyesters, and vinyls are included. One adhesive being used for cellulosic overlays is a thermosetting vinyl emulsion. It is applied experimentally in spreads of 10 to 12 pounds per thousand square feet with a wire-bound bar spreader. Heating the overlay surface has been found to hasten adhesion. Joints of good quality are being obtained, judging by early results of accelerated laboratory evaluations and short-term exposures.

Durability of Melamine Adhesives

The durability of melamine resin adhesives has come under question within recent years in findings reported by some research workers elsewhere. These reports prompted re-examination and preparation of a research paper on some durability evaluations of these glues under way at FPL for as long as 20 years. Performance of high-temperature-setting melamines in the FPL evaluations continues to show up well in both Douglas-fir and red oak laminated beams exposed outdoors unprotected for two decades.

Accelerated Testing of Adhesive Joints

While long-term exposure remains the most reliable way to evaluate adhesives, preservatives, finishes, and

wood products in which they are used, the introduction of new materials and processes cannot be held up until such evaluations can be concluded. Improved accelerated means of assaying new developments are therefore badly needed by industry.

Common ways of evaluating adhesive bonds involve exposure to high temperature, water, and cycles of drastically different conditions such as soaking and drying. Unfortunately, there is no clear relationship between results of these methods and actual service projections over periods of years.

Experiments now under way at FPL on adhesive joints in plywood are designed to unearth such relationships to permit reasonable estimates of potential service from accelerated tests under given conditions. Specimens as nearly identical as possible are exposed to different temperatures, and the loss of shear strength is determined at various periods during the exposure. Some of the specimens are being exposed in the dry condition, others while water-soaked. The water-soaked ones, of course, lose shear strength much more rapidly.

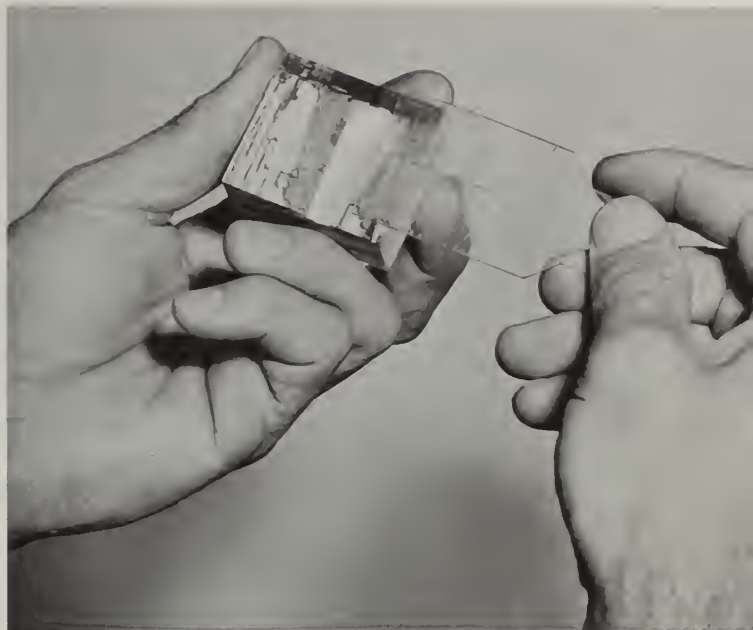
Findings to date show consistent relationships between strength loss and time of exposure by yellow birch specimens made with five adhesives and exposed at 40°, 70° and 100° C. for different lengths of time. The technique used involves the Arrhenius temperature-dependence relationship—in this case, the logarithm of the shear-strength-loss rate constant, as exemplified by the half-life of the specimens, plotted against the reciprocal of the exposure temperature in degrees Kelvin. The half-life was adopted to eliminate variables in shear strength loss that may develop in seriously weakened specimens.

Good straight-line relationships were obtained in data plots for all five adhesives used in the experiments so far concluded with water-soaked specimens of yellow birch. Temperatures as high as the boiling point of water are thus shown not to affect the mechanism of the degradation process as it occurs at lower temperatures.

Experiments are continuing at both higher and lower temperatures and with dry specimens to explore the potentials of this rate-process technique for predicting service life of glue joints made with a range of adhesives. Also under study are the effects of cyclic wetting and drying and the stresses thereby induced in wood and adhesive bonds, which can accelerate shear-strength loss.

Glue-Joint Quality Control

A transparent plastic device marked off in 5-percent increments of various shapes over the area of a standard block shear test specimen was devised as an aid to quality control inspectors by Hans Scharfetter, a South African scientist spending a 6-month training period at FPL in 1965. By laying the device over a tested specimen, the inspector can readily determine the approximate area of wood failure, which is an es-



Clear plastic device marked off in areas of various shapes, each 5 percent of total area, enables inspector to estimate quickly and accurately amount of glue or wood failure in a block-shear glue joint after test. M 128 248

timate of glue bond quality.

Clear Finishes for Wood

The popularity of so-called "natural" finishes for wood used outdoors, such as house siding, trim, and doors, has long had a high potential. Attempts to use these unpigmented coatings, however, have generally been unsatisfactory from the standpoint of long service life. The reason has been traced to photodegradation by light.

Continuing studies at FPL on the nature and cause of this degradation have shown that ultraviolet light, the shortest wavelength band of the visible light spectrum, is a principal cause of failure of both clear finish and the wood underneath it. Chemical experiments on wood have yielded such degradation products as carbon dioxide, carbon monoxide, hydrogen, water, methanol, formaldehyde, and organic acids. During 1965, experiments with ultraviolet at two wavelengths, 2537 and 3500 Angstroms, showed that photo-oxidation occurs at both. Raising the temperatures from 50° to 90° C., however, did not have a significant effect. Irradiation in pure oxygen hastened degradation only slightly, indicating that air has adequate oxygen for efficient photo-oxidation. A commercial ultraviolet light absorber applied to the wood significantly reduced the quantities of degradation products formed.

Physical studies of wood irradiated at both ultraviolet wavelengths revealed the nature of the degradation. Exposure to the shorter wavelength produced rapid, shallow damage; the thin surface walls of some springwood tracheids (cells) of redwood were so completely destroyed that no remaining wood substance

could be seen under the microscope. Clear films of vinylidene fluoride and polyvinyl fluoride, which allow passage of ultraviolet, slowed the rate of damage. A conventional phenolic resin varnish absorbed the ultraviolet but was destroyed by radiation.

The phenolic varnish also filtered most of the longer wavelength radiation without apparent deterioration after 200 days of exposure. Some damage to the wood could be detected, however, in the form of tight micro-checks that suggested shrinkage due to loss of wood substance. A clear silicone resin applied wet did not effectively absorb the longer wavelength ultraviolet. While the resin itself was not damaged after 200 days of exposure, springwood tracheids sustained damage similar to that inflicted on uncoated wood.

Several promising chemical treatments of wood that absorb ultraviolet light at the surface and curb shrinking and swelling are being tried. Among the more effective are copper phosphate, copper naphthenate, sodium chromate, chromic acid, copper chromate, and zinc chromate. All reduced fiber degradation characteristic of weathering and also retarded growth of micro-organisms that discolor wood with mildew.

A lightly pigmented stain finish developed by FPL chemists a decade ago continues to perform well as a natural finish, especially on rough-sawn wood. Western redcedar finished with these stains is still satisfactory in appearance after 10 years of outdoor exposure at Madison.

Environmental Research

The designs and materials used to make a product are in large part governed by the environment in which it will be used. For products in which wood figures prominently, temperature and moisture content are the most important environmental factors. At FPL, therefore, specific studies are directed toward clearer understanding of these phenomena in the various climatic conditions that prevail in the United States.

A device expected to prove of enormous assistance in developing information about temperature and moisture effects on buildings and other wood structures was built by an FPL meteorologist. From government surplus parts costing less than \$1,000, he built an analog computer capable of rapidly solving complex problems such as those involving heat and moisture transfer through walls of houses exposed to any set of climate conditions.

It thus becomes possible, for example, to calculate the effects of any range of temperature on a house built of any material for which the necessary basic data have been determined. For most common building materials these data are well established. From a given set of weather conditions, therefore, the computer can calculate temperature and moisture data for any combination of building materials used for interior and exterior sheathing and finish, insulation, vapor barrier, and the like.

Among major construction problems which this



Meteorologist Gene Wengert checks out analog computer he built to calculate heat flow through walls from data on climate and properties of materials used in wall construction.

M 130 229

computer will help solve are those concerning the effects of air conditioning on houses. It is known that in the humid heat of summer serious moisture content problems can develop in flooring, interior millwork, and other wood parts. Little has been done, however, to ascertain how air conditioning influences this and related problems.

Conditions that permit moisture condensation, as when highly humid air is drastically cooled, are among those to be studied with relation to their effects on wood and wood-base building materials. Where such conditions prevail over extended periods of time, as in the

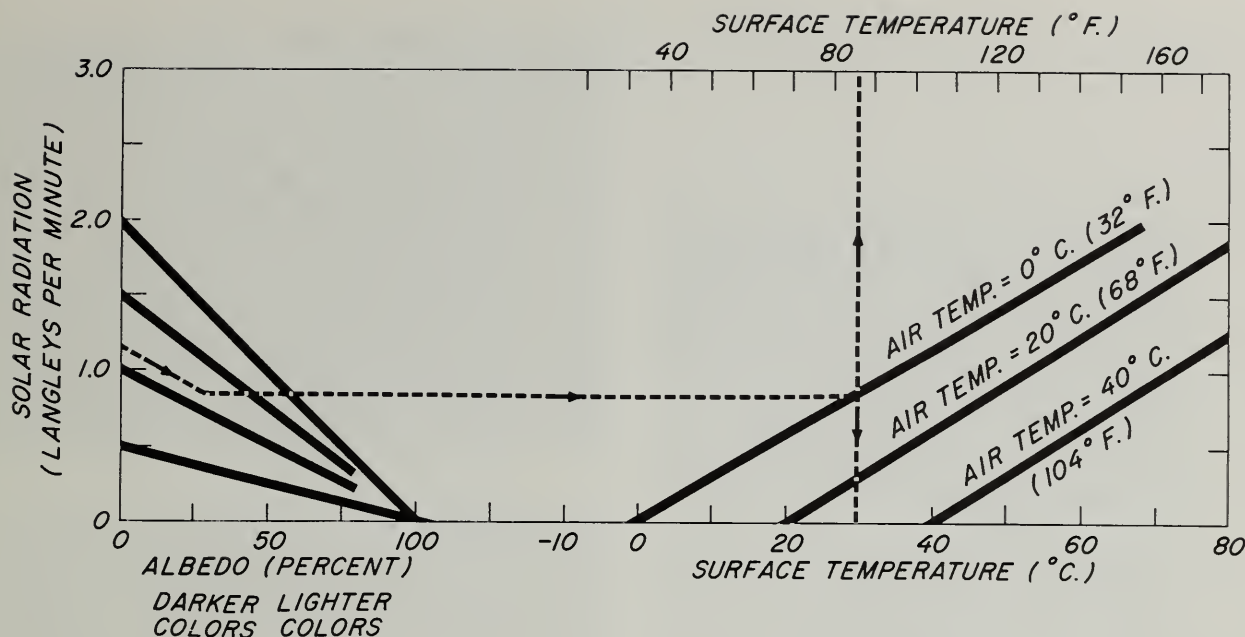


Chart for predicting maximum surface temperatures of a material exposed to exterior conditions. The dashed line is an example of its use by locating the solar radiation value on the left margin, following a diagonal line to the intersection with the proper albedo (reflectance) value, then moving horizontally to the intersection with the proper air temperature. The maximum surface temperature is determined by reading vertically up for temperature in Fahrenheit degrees or down for Celcius degrees.

M 129 854

Southern and Southeastern States, the hazard appears to be most acute. Work during 1966 will be concentrated, therefore, in the Southeast in cooperation with the Southeastern Forest Experiment Station's Research Center at Athens, Ga.

Meanwhile, important information on temperature and moisture effects in building walls during the winter months at Madison was obtained during the past year. Various heating, humidification, and climatic factors were compared in an exposure structure designed and built for the purpose. An automatic moisture content recording system accumulated daily records of moisture fluctuations at many points in the walls. The results pointed up the importance of a good vapor barrier, well installed, in light frame construction. Even slight damage was shown to impair the barrier's efficiency.

A wood porch on the same structure is yielding significant information about the cause of decay, which frequently shortens the service life of such structures. Moisture, of course, is the villain. Rain penetrates paint coatings which break over nails, or where the wood underneath checks or splits, or at joints where two boards butt together. Once in the wood, the moisture diffuses along the grain for several inches. Wood protected with a good water-repellent preservative before it was painted was much less likely to take on moisture in damaging amounts. Brush or dip treatment with water-repellent preservative is highly recommended for such parts as the floors and steps of porches.

How hot a wood surface will get outdoors can now be calculated readily by a simple, accurate method developed by FPL environmental research. Only data on the maximum daily temperature of the area and the solar radiation received are needed. A graphic representation of the method permits quick determination of surface temperatures when the reflectivity of the surface, based on its color, is known. Colors vary widely in reflectance. Black is rated at 2 percent reflectance (98 percent absorption) while white titanium dioxide paint has a reflectance value of 85 percent.

Basis for the graphic method is an energy balance equation that was experimentally checked out and shown to be quite accurate for predicting maximum temperatures of wood products in various conditions of exposure. Maximum temperatures measured with instruments in a wood roof under shingles of four different color combinations coincided quite closely with maximum temperatures calculated by the energy balance equation over a range of maximum air temperature from -5° to $+40^{\circ}$ C.

Patents

Public use patents were granted to two FPL staff members in 1965. One, Patent No. 3,173,460, was given Robert A. Hann for invention of a process for reducing springback in pressed wood products. The other, Patent No. 3,174,192, was granted to Bruce G. Heebink to cover invention of a siding attachment to buildings.

WOOD CHEMISTRY RESEARCH

The many-faceted nature of wood chemistry research was demonstrated during 1965 by the broad variety of urgent wood-use problems under study at FPL. A noteworthy accomplishment was the demonstration, by means of physical chemistry techniques and principles, that wood can be coated much more successfully and durably with clear natural finishes when its surfaces are chemically modified. Strong evidence was obtained that surface treatment with phenolic resin both stabilizes the surface layers of wood against the swelling effects of moisture and effectively absorbs ultraviolet light, the deteriorating effects of which on wood are well authenticated.

Other developments during the year also demonstrated the wide-ranging applications of chemistry research. Among these were:

1. Biochemical studies of deterioration of wood pulp chips stored outdoors, which suggested new methods of controlling and lessening the damage often incurred with this economically advantageous and increasingly popular method of storage.
2. Establishment of a laboratory at Muscle Shoals,

Dr. M. A. Millett, FPL chemist, describes thin-layer chromatographic techniques he developed for analyzing microquantities of unknowns to Dr. Lea Valtasaari, cellulose chemist at State Institute for Technical Research, Helsinki, Finland. Dr. Valtasaari conducted research planned by Dr. Millett on new method of measuring cellulose chain length financed in part with counterpart funds available under Public Law 480 from sale of surplus agricultural products in Finland by U. S. Department of Agriculture.

Ala., jointly with the Tennessee Valley Authority for research in fire retardants for wood and improved processes for chemical utilization of hardwoods.

3. Basic work on wood carbohydrates by an FPL chemist during a year's post-doctoral study in Sweden, which shed new light on the stability of hemicelluloses in alkaline pulping solutions.
4. Verification that free radicals—chemical entities containing an unpaired electron—have an important role in deciphering the molecular structure of lignin.

Surface Treatment for Clear Finish

Surface treatment of wood with phenolic resin was shown to furnish a much improved foundation for clear finishes that do not absorb ultraviolet light. Experiments comparing such a finish with one that does absorb ultraviolet convincingly demonstrated the superiority of the nonabsorbent finish.

The research was conducted in cooperation with the National Forest Products Association and the National Paint, Varnish and Lacquer Association to find more durable natural finishes for wood used outdoors, such as house siding and trim. The physico-chemical solution sought for this problem was to improve the dimensional stability—that is, resistance to swelling and shrinking under wet and dry conditions—of the wood surface as a base for finish, on the assumption that dimensional changes stretch or compress the film of finish.

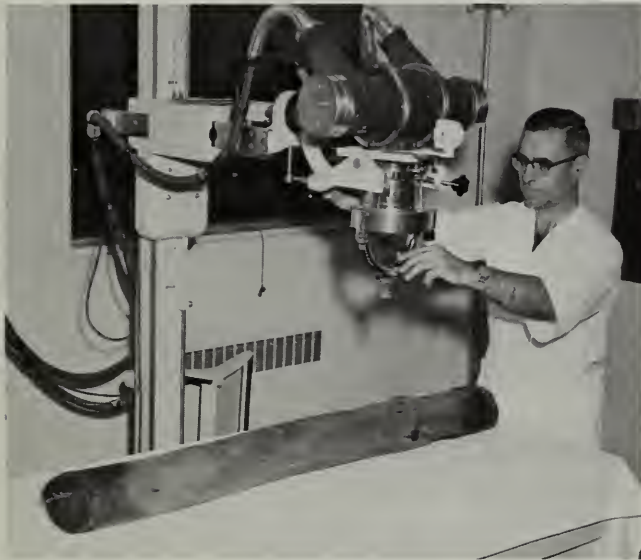
Past research had shown that phenolic resin impregnation of the cell walls of wood is a highly effective way of dimensionally stabilizing wood. That research, however, had stressed complete impregnation. The new approach undertaken—with the object of lessening treatment costs—was to stabilize only the surface zones of the wood.

Early experiments were conducted with an oil-modified polyurethane varnish. This finish was tried on ponderosa pine, southern pine, and redwood. The surfaces of all three species were first stabilized with a 17 percent water solution of phenolic resin, some specimens being given a diffusion treatment for one-half hour and others a 5-minute pressure treatment. All were then varnished with a brush.

Exposure consisted of a simulated weathering cycle of 102 minutes in carbon-arc ultraviolet light and 18 minutes of water spray every 2 hours for 20 hours, followed by a 3-hour water spray and 1 hour at 0° F. This cycle was repeated for up to 12 weeks with some specimens.

The polyurethane varnish became embrittled and checked to varying degrees on all three species, unmistakable signs of breakdown appearing within 6





A limb from a plane tree on the Grecian Isle of Cos under which legend says that Hippocrates, the Father of Medicine, taught 24 centuries ago, was obtained by the American College of Physicians through diplomatic channels. For advice on how best to convert it into a shaft of a ceremonial mace for use when inducting new Fellows, Dr. Theodore Abernethy, Washington, D. C., a College vice president, was referred to FPL. X-rays by Raymond Cooper, technician at Madison, Wis., Veterans Administration Hospital, revealed hidden decay. Limb was slabbed and turned to shaft dimensions by Carpenter Ed Meyer, shown examining decayed portion with Chemist Ray Seborg preparatory to replacing it. Turned-down shaft was treated with polyethylene glycol by Seborg to stabilize dimensions. Finished mace with gold and silver head and base and sculptured shaft is admired by Dr. Abernethy and Dr. Irving S. Wright, Cornell University School of Medicine, New York. M 129 109 M 127 057 M 127 118 M 124 567 M 128 200

to 8 weeks, although sometimes the checking could be detected only under the microscope. It was apparent that the varnish was damaged by ultraviolet radiation.

Other experiments having shown that polyurethane absorbs ultraviolet at wavelengths of 4,000 Angstrom units or less, it was decided to try a finish that does not absorb ultraviolet. A polyalkyl methacrylate emulsion was chosen for this work.

The methacrylate was tried on both diffusion-treated and pressure-treated specimens of ponderosa and southern pine with excellent results. After 8 weeks of exposure to the laboratory conditions, no checking was detected in either the finish or the ponderosa pine. A few bleached streaks appeared. Microscopic examination showed that they occurred over the exposed cavities of cells that had been split open at the surface by machining. It was hypothesized that, when the methacrylate finish was applied, some air was trapped in these hollows, which were bridged over rather than completely filled with finish. When the specimens were exposed to light, photo-oxidation may have stimulated the bleaching effect.

On the southern pine specimens slight yellowing was evident at the interface between finish and wood, but the methacrylate did not undergo even micro-checking such as had occurred in the polyurethane varnish. Again, bleach streaks appeared where the finish had bridged over exposed cell cavities when brushed on the wood.

The relatively superior performance of the nonabsorbent polyacrylate as compared with that of the ultraviolet-absorbent polyurethane points to a new approach to design of clear wood finishes for outdoor use. Since the ultraviolet passes through the polycrylate, yet does not damage the wood underneath, it appears logical that the phenolic resin performs a function in addition to that of dimensional stabilizer of the wood. The evidence points to the conclusion that the phenolic resin absorbs the ultraviolet and in turn dissipates it harmlessly as heat.

Long-term experiments are now under way outdoors on specimens treated with the phenolic resin by both methods—some by diffusion and some by pressure treatment. These are essential because there is no way of quantitatively relating the laboratory exposure conditions to normal climatic conditions of sun, rain, heat, and cold.

Pulpwood Chip Storage

In a cooperative study with a pulpmill in Maine, the Northeastern Station, and the Forest Products Laboratory, the reactions taking place and the conditions existing in an industrial-size chip pile were studied. Chip storage differs from roundwood storage in that chip piles heat up, while roundwood does not. The rise in temperature is great enough to inhibit the development of the true wood rot fungi in certain portions of the pile. There is a wide temperature range from the exterior to the interior of the pile, so that a



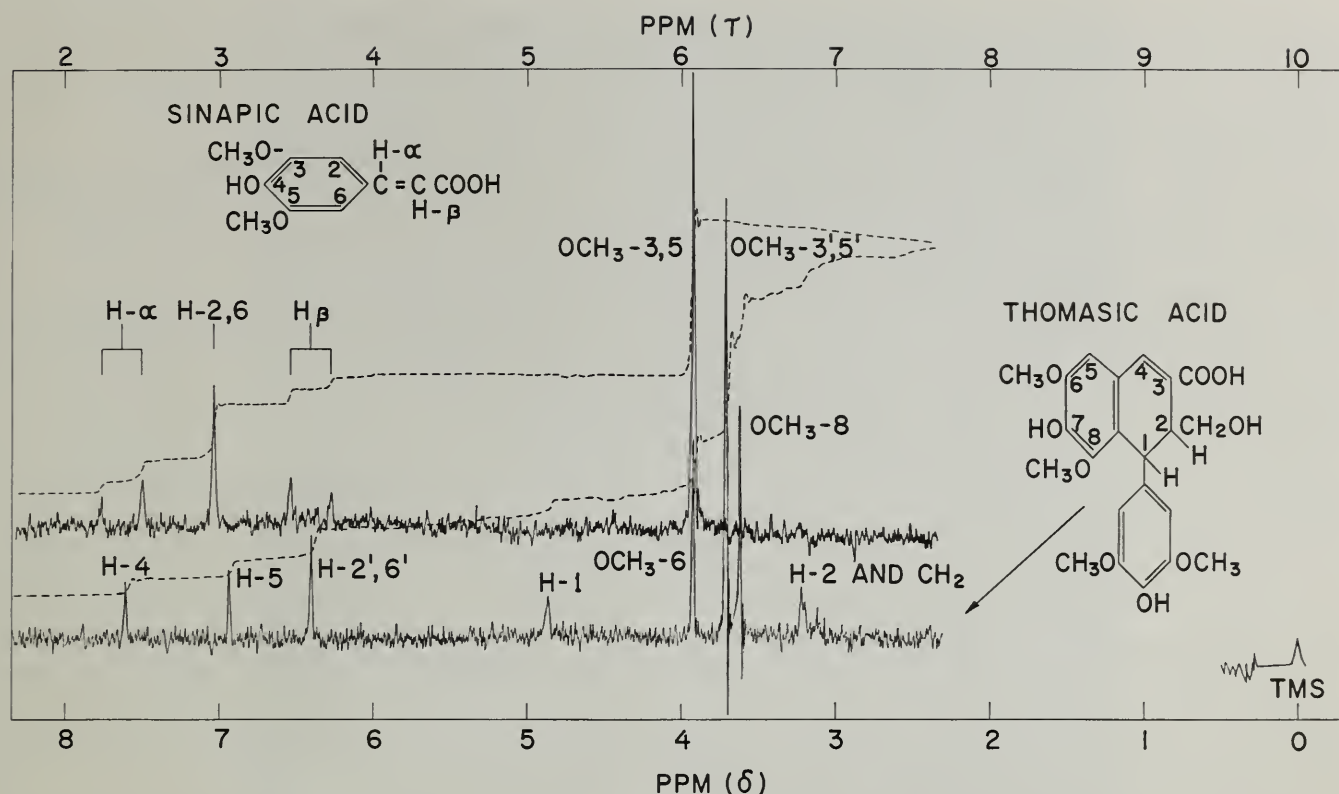
Pulp sheets made of stored hardwood chips are prepared by Technician Henry Grimes for analysis of storage effects on pulp brightness, other properties. M 130 507

wide variety of micro-organisms are encountered. In the cooler portions of the pile, the usual wood rots find satisfactory growth conditions. In the warmer sections of the pile, the usual wood decay fungi are replaced by thermophilic organisms not normally encountered in roundwood decay.

Loss in wood substance, as measured by direct weighing and density determinations, amounted to about 6 percent in 6 months of storage. Losses of wood extractives amounted to 50 percent in 6 months of storage. Oxidation of the extractives caused discoloration of the chips and the rapid temperature rise in the chip pile. No change was found in the lignin-carbohydrate ratio of the stored chips.

There was a definite decrease in sulfite pulp yield, as well as a decrease in pulp brightness, so that increased quantities of chlorine were required for bleaching. On the other hand, there was no significant trend noted in the physical properties of the unbleached and bleached pulps due to wood storage.

The most interesting and surprising fact which this study revealed is the rapidity with which these detrimental effects take place. Discoloration of chips and loss of pulp yield and brightness were apparent after only 1 month of storage in the chip pile.



Marked similarity of nuclear magnetic resonance spectra of sinapic acid to that of unknown crystalline substance from rock elm extract led to unique three-ring structure of new substance tentatively named thomasic acid. M 130 179

Preliminary studies in which the chips were treated with a variety of antioxidant, fungicidal, and enzyme-inhibiting chemicals in order to control chip discoloration and wood loss were made. The most promising treatments are being further evaluated.

Nylon column chromatography apparatus for separating thomasic acid crystals from rock elm aqueous extract is operated by Chemist Frances Hostettler. M 138 183



The scattered literature on outdoor storage of pulpwood chips was collected, and a review and bibliography was prepared.

Free Radicals in Lignin

The demonstration that free radicals exist in wood preparations (see 1964 Annual Report) and that free radicals can be synthesized by the oxidation of lignin model compounds has provided experimental support for theoretical postulations that these chemical entities are involved in the formation of lignin through biosynthetic processes in the tree. The work of Dr. Cornelius Steelink, chemist at the University of Arizona, while on sabbatical leave at FPL during the academic year 1964-65 contributed substantially to this concept of lignin formation.

Dr. Steelink's work at FPL, where he joined a pioneering research team devoted to the study of lignin, demonstrated that certain model compounds believed to represent segments of the extremely complex lignin molecule can be converted to relatively stable free radicals by oxidation. Such radicals, possessing an unpaired electron, can be measured with an electron paramagnetic resonance spectrometer. The detailed spectrograms obtained through the courtesy of the University of Wisconsin proved to be distinctive for each compound, hence they provide identification "signatures." Such advanced instrumentation is of great importance in studying free radicals and their reactions.

It has long been theorized that lignin biosynthesis in the tree is in some part the result of free radical formation from coniferyl alcohol followed by its polymerization. Coniferyl alcohol is a chemical constituent of the growing portion of a tree.

The stability of free radicals from lignin model compounds offers important support to present theories of lignin biosynthesis.

Dr. Steelink's work in securing relatively stable free radicals was particularly successful with the family of model compounds known as syringols. These are thought to constitute a major portion of the molecular structure of hardwood lignin. Model compounds related to softwood lignins, the guaiacols, either failed to respond at all or responded too rapidly to provide measurable amounts of free radicals. In nature, free radicals may appear and disappear almost instantaneously in biosynthetic processes.

Dr. Steelink is continuing his work at the University of Arizona with support of a Forest Service grant.

FPL-TVA Research Unit

In collaboration with the Tennessee Valley Authority, a research unit has been established at Muscle Shoals, Ala., for work on new wood fire retardants and chemical utilization of hardwoods. Leader of the unit is Ira T. Clark, FPL chemist with broad experience in research ranging from basic studies of lignin to military explosives and rocket propellants. Chemists at TVA's National Fertilizer Development Center in Muscle Shoals will cooperate. Basic chemicals in fertilizers will be used in experiments seeking better fire retardants.

Unique Acid from Elm

An aqueous extract of rock elm originally regarded as important mainly for species identification because of its singular fluorescent properties in ultraviolet light turned out to contain at least one, and possibly more, unique new compounds.

Tentatively named thomasic acid after the botanical name of the tree from which it was derived, *Ulmus thomasi*, the new compound thus far studied was found to have a molecular structure unique among its class of substances, the lignans. Its uniqueness results from the fact that it possesses a double bond, a free carboxyl group, and a third complete ring. Other lignans now known to chemists have two, but not all three.

Because it closely resembled other common compounds, especially in its fluorescent properties, it was at first supposed to be one of a class of acids and acid derivatives widespread in nature, such as chlorogenic acid, which occurs in tobacco. But such identification methods as paper chromatography, ultraviolet and infrared spectra failed to confirm this supposition.

It became necessary, therefore, to obtain the compound in pure state for further analytical study. This turned out to be relatively simple; chromatographic separation in a nylon column produced white crystals which, when placed in a nuclear magnetic resonance

spectrometer, yielded a trace with unmistakably unique structure characteristics. From this trace the compound's molecular structure was postulated. Thomasic acid comprises about 0.2 percent of wood by weight and is a relatively strong acid.

Other compounds separated from the same extract are being similarly studied as part of FPL's continuing basic research on extractives of wood and bark.

Carbohydrate Chemistry

Research on the mechanism of decomposition involved in alkaline pulping of wood has thrown new light on the rate at which carbohydrates are solubilized and destroyed.

While these studies are purely basic, designed to find out what happens, they have significance in all chemical processing of wood by alkaline treatments to disassociate its principle chemical components, cellulose, hemicellulose, and lignin, from one another. Kraft pulping, for example, by which most paper is produced, is an alkaline process that solubilizes some cellulose and much of the hemicellulose in wood. Better knowledge of how wood behaves in alkaline liquors might point the way to modifications of the kraft process by which substantial tonnages of wood substance might be saved for use.

Alkali converts cellulose and hemicellulose to saccharinic acids. Theoretically hemicellulose decomposition should be arrested by the formation of certain intermediate substances. In actual pulping, however, a large percentage of it decomposes. Resolution of this conflict between theory and practice is one of the objectives of the work.

In furtherance of this research, Dr. Milton S. Feather, FPL chemist, spent a year at the Swedish Forest Products Laboratory in Stockholm to work with Dr. Bengt Lindberg, internationally known carbohydrate chemist who heads that Laboratory's wood chemistry division. During that time, Dr. Feather made substantial progress on rate studies of the alkaline decomposition process. Since returning to FPL in September 1965 he has continued this work.

In Sweden, Dr. Feather experimented with model compounds consisting of partially methylated glucose and cellobiose derivatives. These compounds have linkages and modes of attachment somewhat similar to certain vulnerable points in hemicellulose molecules. These yielded the rate data on decomposition in alkali.

Following up his findings with model compounds, Dr. Feather is now working with hemicellulose from white birch, which is obtainable in a relatively pure state. At some point in the decomposition, he hopes to interrupt the process in order to study the intermediates formed and thus gain more insight into the mechanism of the chemical progression involved.

Cement-Excelsior Board

Manufacturers of a panel material made of excelsior bonded together with Portland cement and used as roof decking and curtain walls of buildings consulted



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Using platinum black catalyst, Dr. Milton Feather oxidizes methyl glucoside in attempt to synthesize uronic acid for use in decomposition studies of wood carbohydrates.
M 130 340

FPL chemists concerning erratic curing of the cement during production. A major cause of abnormally slow curing was traced to the presence of decayed wood in some batches. Decay is thought to interfere with curing because of fungal breakdown of the cellulose in wood to the point where it becomes soluble in the strongly alkaline cement at a pH of around 12.5. Passages opened in wood by burrowing of fungus hyphae also permit penetration of the alkali into the wood, facili-

tating extraction of inhibitors. A quick assay procedure based on the curing time of cement was devised to permit manufacturers to determine the curing time of different cement-excelsior mixtures. Softwoods are usually preferred because hardwoods contain hemicelluloses, which are especially vulnerable to attack in an alkaline medium. Aspen, a low-density hardwood, is, however, used successfully in the product.

WOOD FIBER PRODUCTS RESEARCH

The mounting urgency of the search for better means to control and eliminate pollution of air and water—clearly mirrored in government action at local, State, regional, and national levels—has been anticipated in FPL research on pulp and paper processes over the past several years. As a consequence, effective and less costly methods of reducing the amounts of effluent and other residues that must be disposed of are at or near the stage of commercial practicality. A resume of these processes, on all of which work was pushed during 1965, is presented here.

Among other wood fiber products research on which noteworthy progress was made during the past year, the following stand out:

1. Groundwood-type chemimechanical pulps produced from light-colored hardwood chips treated with alkaline sulfite liquor were shown to have unusually good brightness for this type of pulp.
2. One handicap of hardwood pulps tending to hold down their utilization—the low strength of the wet web on the paper machine—was lessened by mechanical processing of the pulp and use of new rubber compounds on paper machine rolls.
3. A new method was developed for studying fiber-to-fiber bonding in pulp sheets by measuring the electrical conductivity of the sheets.
4. Another step toward better tailoring of paper for intended uses was achieved with a new procedure for altering the porosity of the sheet on the paper machine.
5. Paper's edgewise compressive strength, a fundamental mechanical property, was found to be susceptible to considerable improvement on the paper machine.

Reducing Water Pollution

One of FPL's major research objectives is to discover and develop high-yield pulping processes. This is accomplished generally by finding more selective pulping chemicals, so that less wood substance is lost in the spent pulping liquor. Criteria sought include low chemical requirement, mild treatment, and simple processing procedures. Primary considerations also include economical recovery of pulping chemicals and convenient disposal of mill effluents free of pollution hazards.

The types of pulping processes now in common use are mechanical and chemical or various combinations of the two. Virtually all of the wood is converted to pulp by mechanical grinding; it is a weak, but bulky fiber desirable for printability and absorbency as in newsprint, various printing papers, and tissue. To get the strong papers needed for bag, wrapping, and box-board and the bright white papers for books, magazines, tissues, and the like, however, chemical process-

ing is necessary to separate the relatively long cellulose and hemicellulose and the cement-like lignin that binds the fibers together and to one another. Conventional chemical processes, notably kraft and sulfite, convert some 45 to 50 percent of the wood, by weight, to pulp.

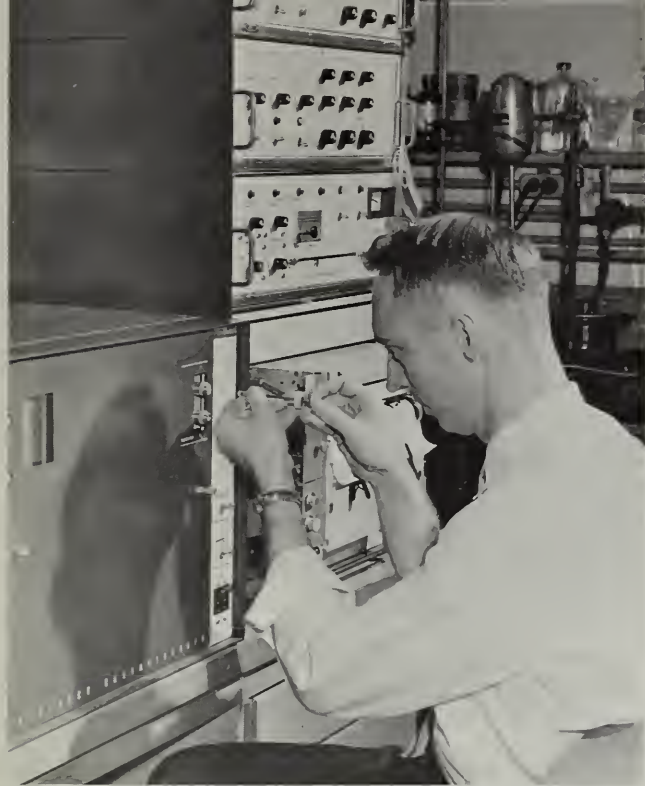
Combinations of chemical and mechanical pulping, known as chemimechanical (80 to 92 percent yield) and semichemical (55 to 80 percent yield) processes, produce usable pulp in yields somewhere between the 55 percent of the chemical processes and the 95 percent of the groundwood processes. Because these pulps contain substantial amounts of lignin, their bleaching quality and strength are lowered. Outstanding among these processes has been the FPL neutral sulfite semichemical process, now extensively used to pulp hardwoods in yields of 70 to 75 percent. A rather stiff paper is made from this pulp. Its principal use is for corrugating medium in containerboard; for the flat liner sheets to which the corrugated sheet is glued, kraft paper is used for reasons of strength.

Over the years since NSSC was originated in the mid-twenties, FPL scientists have greatly expanded its utility by bleaching and other treatments. It is now used in considerable quantities for magazine stock and, in mixture with other pulps, for a variety of printing and writing papers.

The major contribution of NSSC to the alleviation of pollution has been the reduction of wood dissolved by producing greater yields of pulp from a given quantity of wood. This trend was stepped up still further during the 1950's by the introduction of FPL's cold soda process, a chemimechanical process capable of yields up to 95 percent. The main use of cold soda hardwood pulp so far has been in container board, newsprint, and printing and writing papers.

By far the largest tonnages of pulp, however, are still produced by chemical pulping. More than half of all wood pulp is made by the kraft process. Recent FPL research has shown that kraft-type pulp yields can be raised as much as 25 percent by use of the new polysulfide process (see 1963 and 1964 Annual Reports).

A new recovery process that facilitates reuse of the chemicals in the sulfur-enriched polysulfide pulping liquor enhances the economic attractiveness of the polysulfide process. In addition to cost reduction, however, the recovery process contributes to alleviation of pollution. Essentially, this process consists of recapturing hydrogen sulfide generated in the digester during pulping, and of reconversion of the spent liquor by evaporation, oxidization to sodium sulfate, and reduction to sodium sulfide. Work during the past year showed that rate of removal of hydrogen sulfide from black (spent) liquor by stripping was found to be increased at higher temperatures, by controlling the pH



Dr. James Minor injects into gas chromatographic apparatus a syringe full of chemicals obtained by reacting polysulfide liquor with model compounds of wood polysaccharides.

M 130 508

between 10.7 and 11 with addition of carbon dioxide, and by adding nitrogen to the stream during stripping to act as a carrier gas. The more efficient stripping not only reduces recovery process time but makes smaller and less costly recovery equipment feasible.

Also under study is the practicality of newly developed commercial fluidized-bed reactors for the combustion of polysulfide spent liquors and production of sodium sulfide.

NSSC and other high-yield pulping processes present similar spent-liquor recovery problems. By use of a magnesium base instead of sodium, chemical recovery from spent liquor is simplified and substantially lowered in cost. Magnesia-base semichemical pulping is made practical by either two-stage pulping—a bisulfite first stage at pH of 4 to 5, followed by a short neutralization stage—or by use of small quantities of ammonia as an alkaline buffer in single-stage pulping. Both modifications produced pulps that can be made into boards equivalent in properties to those from NSSC pulps. Fluidized-bed reactors for burning spent liquor present added possibilities for reducing capital cost and simplifying magnesia-base recovery.

Less well advanced but commercially promising is a new, simplified, and less costly process for recovering NSSC soda-base pulp chemicals. This process is based on direct oxidization of smelt obtained by burning the NSSC liquor alone or together with kraft black liquor in a kraft recovery furnace. The oxidized smelt is suitable for reuse in NSSC pulping.

This method is also suitable for recovery of chemicals from alkaline sulfite spent liquor. The alkaline sul-

fite pulping process is known to produce very strong pulp from softwoods, but its industrial development has been held back for lack of a suitable chemical recovery system. The new NSSC recovery process for soda-base liquor gives promise of filling this need.

The economic potential of the process for small NSSC mills is, however, of greatest immediate significance. The cost of recovery processes now available is prohibitive—some \$4 million for a 200-ton mill. The new magnesia-base NSSC recovery process should cost only a fraction of this amount; best estimates now available run less than \$1 million—a figure that should bring pollution control much nearer attainment for these mills.

Chemicals that can add to pollution hazards are also used to improve strength, water resistance, printing, and other properties. They are commonly added to the pulp furnish just before it is run through the paper machine, in the belief that this is necessary to distribute them through the paper sheet. Some of these chemical additives are lost in the drainage water along with small amounts of wood substance.

FPL experiments have shown that additives can be applied to the paper sheet as it is being formed on the machine. In fact, addition at this stage in production is more effective than mixing with the furnish because none of the additive is lost. Chemicals so applied can be made to penetrate the sheet with proper control of sheet moisture content, viscosity of the additive, and press pressure. A cooked starch of normal viscosity, for example, will penetrate completely a sheet having a moisture content above 15 percent.

Continued improvement of recovery processes is a major segment of FPL wood fiber products research. Looking to more distant needs, basic research on the reactions of hemicellulose with pulping agents is under way. A major object of this fundamental work is to determine how changes in hemicellulose structure affect yield and properties of pulps.

Among studies well under way is one on the reactions of model compounds representing typical hemicellulose fractions with polysulfide pulping liquor. The yield gains possible with polysulfide over conventional kraft pulping have been found to be due to the selective oxidization of reducing end groups of the hemicellulose molecule, thereby making the glucomannan fraction more resistant to alkaline degradation. Similar stabilizing of other hemicellulose fractions would further increase pulp yields. Paper and gas chromatography are being used to separate, identify, and analyze the reaction products of the model compounds with polysulfide liquor.

This study has shown that the alkali strength of the pulping liquor has a pronounced effect on sugar losses. Alkaline sulfite liquor with a terminal pH of 10 changed the ratio of sugar residues in 4-O-methylglucuronarabinoxylan of white spruce pulp only moderately; per 37 xylan units, the number of uronic anhydride units

dropped from the 6.2 of normal wood to 5.2, while the number of arabinose units was lowered from 5.6 to 4.8. Polysulfide liquor at a pH of 12 dropped the number of uronic anhydride units to 2.2 and that of arabinose to 3.4, and kraft liquor reduced the numbers still further, to 1.2 and 1.9 respectively for the uronic and arabinose residues.

One significant advantage of pulps whose xylan contents include a greater number of substituents was their reduced energy requirement for beating and faster strength development.

Pulping Appalachia Hardwoods

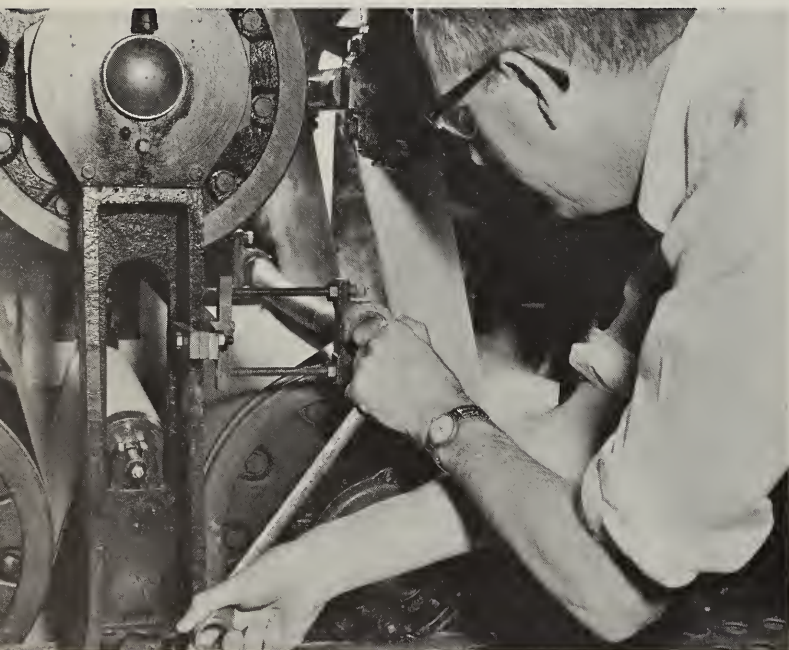
Much of the Appalachia region, as defined by the Appalachian Regional Development Act of 1965, has large supplies of timber, principally hardwood, for which there is little market because of its size and quality. Much is of pulpwood size, however, and to develop such markets FPL was allotted funds under the provisions of the 1965 Act for research on suitable pulping and papermaking processes and techniques.

As a start, research on processes suitable for converting these hardwoods into sanitary tissue and towel papers was singled out because only two mills on the northern fringes of the region now make such a product and neither makes pulp. Since one object of the research is to supply the technical basis for industrial development of the region, a centrally located pulp and paper mill would, it was considered, be a significant contribution to the regional economy.

Research has been initiated with studies of sulfate pulping of typical mixtures of some Appalachian hard-

Technologist Donald Fahey adjusts bow of expander roll experimentally located in press section of FPL paper machine to establish widening effects of roll on hardwood kraft linerboard being produced on machine.

M 130 506



woods—oaks, hickories, maple, and yellow-poplar—designed to produce soft, absorbent pulp. Papermaking studies will be aimed at production of semidry and dry-creped toilet and facial tissue and semidry and wet-creped towel papers.

Groundwood-Type Hardwood Pulps

By selecting those hardwoods which yield light-colored pulps, chemimechanical pulping appears to hold considerable promise for producing newsprint and similar papers that require only moderate brightness. Experiments with white birch and sweetgum produced pulps in the brightness range of 60 to 65 percent, which easily meets the requirement for newsprint.

Chemical treatment to soften the chips consisted of cooking in alkaline sulfite liquor at a moderate temperature, 85° to 110° C. The softened chips were fiberized in a refiner. Yields of 88 to 92 percent were obtained. Opacity of the pulps was moderately high, varying greatly with degree of chemical pretreatment and brightness.

Other light-colored hardwoods for which this chemimechanical process appears suitable include aspen, cottonwood, some maples, yellow-poplar and some tupelos. While economic conditions may not yet be ripe for such a process, future requirements for paper coupled with rising pulpwood prices and the necessity of utilizing more hardwood for pulp may well create conditions more favorable to its commercial usefulness. The most practical use of such hardwood pulps would appear to be in various printing and writing papers, foodboard, tissue and toweling.

Fiber-to-Fiber Bonds

The formation of paper sheets is dependent upon the linking together of individual pulp fibers. Paper properties are greatly dependent upon the bonds formed between fibers. The mechanism is known as hydrogen bonding (see 1964 Annual Report).

During 1965, research was conducted on the fiber bonding of balsam fir sodium bisulfite pulps of various yields. These yields ranged from about 51 percent for a fully digested pulp to 94 percent for a mildly cooked pulp (the extent of chemical digestion governs the yield, more hemicellulose and lignin being retained in the higher yield pulps).

Fiber characteristics change markedly as yield increases. Fibers are stiffer in the higher yield pulps because they are coated with lignin. Hydrogen bonding is dependent upon exposure of cellulose, especially the inner cellulose-rich layers of the fiber wall, because it is the cellulose which contains the hydroxyl groups capable of hydrogen linkage. The more complete the removal of lignin by prolonged cooking, therefore, the more cellulose is exposed. The fibers also become more conformable, hence denser paper sheets can be formed that have higher tensile and folding strength. On the other hand, the stiffer lignin-coated fibers of high-yield pulps produce paper of greater tearing strength and stiffness.

Fibers of high- and relatively low-yield pulps were also processed in a beater and then examined under a scanning electron microscope. Micrographs clearly showed the effects of such processing. Fibers of the high-yield pulp were not fibrillated by beating but were torn and split so that film-like lamellar-type bonds were formed between fibers. Sheet structure remained open because the stiff fibers did not conform well to each other.

In the fibers of the lower-yield pulp, beating exposed the inner portions of the fiber walls, which improved possibilities for hydrogen bonding of hydroxyl groups in the cellulose-rich inner layers of the walls. Many of the hollow fibers collapsed, thereby increasing contact area with other fibers. Extensive fibrillation (loosening of fibrils in the cell walls) also promoted bonding. Sheet structure was denser.

Examination of the pulps under ultraviolet light revealed further information about the distribution of lignin in the fiber walls. Micrographs clearly showed the heavy lignin content incrusting the high-yield pulp fibers, whereas those of the lower-yield pulp were revealed to be relatively free of lignin and therefore much more likely to form hydrogen bonds.

A new method of determining the extent of the surface area of fibers bonded together by measuring the electrical conductivity of the pulp sheets is being investigated. The method is based on the hypothesis that highly bonded sheets are better electrical conductors than poorly bonded sheets. Cellophane is the basis ma-

terial for evaluation; being cast of pure cellulose, it is assumed to be 100 percent bonded.

Bleaching High-Yield Pulps

Experiments with new ways of bleaching the normally dark high-yield hardwood pulps to improve their suitability for white papers have shown that potassium hydroxide is an effective decolorizer of heartwood. Means of utilizing this discovery in more efficient bleaching processes are being explored.

The color bodies responsible for the dark pulp color are located mainly in the parenchyma cells of wood, much less frequently in the fibers. Their removal unchanged for study has proved to be extremely complex in experiments with refiner groundwood and hot sulfite pulps made of birch sapwood heartwood. The all-sapwood pulps, like the wood itself, are relatively bright. The all-heartwood pulps are deeply colored by brownish-red extractives.

Removal of the extractives without chemically altering them is necessary to identify them chemically and experiment with various chemical treatments that may modify them and brighten their color, as a prelude to more effective bleaching methods.

Porosity Control in Papermaking

New experimental techniques for controlling the porosity of the paper web while it is being formed on the paper machine promise more efficient production of a broader range of paper grades. The techniques have proved workable on the FPL paper machine.

Shielded in copper screening to keep out unwanted electrical signals, strip of paper is tested for electrical conductivity in device for measuring relative fiber bonding area developed by Technologist William Smith.

M 130 509



The more porous the sheet, the faster it releases its water in the press and dryer sections of the paper machine, thus lowering production costs. For some uses, however, too porous a sheet is unsuitable.

Experiments have shown that porosity can be increased by using an expander roll in the press section to stretch the web, thus promoting moisture release. Conversely, porosity can be reduced to any degree by applying starch to the surface of a sheet with controlled moisture content. The amount of starch applied determines the thickness of the film and resistance to air movement through the sheet.

Starch mixtures of high viscosity are best for increasing film thicknesses on dry paper. Low-viscosity starches do not reduce porosity if applied to papers that are above 15 percent in moisture content.

Besides cutting production costs and broadening the range of porosity possible to achieve in papers, the new techniques should reduce the amounts of off-quality paper produced and the consequent increase in fiber losses that must be disposed of in papermill effluent.

A related papermaking problem that holds back use of hardwood pulps involves the low tensile and surface strength of the wet web as it passes through the machine. Frequently the web is not strong enough to overcome the adhesive forces that hold it to the rolls over which it must pass.

Studies have shown that mechanical processing of the fibers increases the tensile and surface strength of the web substantially more than it does the adhesive forces. Coupled with this finding is evidence that new rubber compounds which exert less adhesive force can be used for roll surfaces. In combination, these findings give promise of distinctly more favorable press conditions for sheet forming and processing with hardwood

pulps. On the other hand, pressures applied to the wet webs increased adhesive forces about as much as they did web tensile and surface strength, hence offered no advantage.

Engineering Properties of Paper

Edgewise compressive strength—a basic mechanical property of paper—can be improved without adding fiber or chemicals, experiments with one pulp indicate. Handsheets made of the pulp gained 60 percent in this property, as well as 130 percent in stiffness, when restrained from shrinking during drying. Earlier work (see 1963 Annual Report) had shown that stiffness could be markedly improved in this manner, leading to the supposition that compressive strength might also gain. Much the same kind of restraint can be obtained on the paper machine with strategically placed curved expander rolls and by controlling the orientation of fibers in the paper sheet.

Edgewise compressive strength is of particular importance in papers that will be subject, in use, to loads capable of causing either tensile or compressive failure; under such conditions failure invariably occurs in compression.

In studies of stiffness, a basically important property for such products as foodboard, cup stock, and linerboard, data on fiber orientation and drying restraint indicated that stiffness can be predicted and design criteria developed for papers of specified stiffness. Formulas for elastic relations of orthotropic laminates available in the literature were found to be usable in the design of paper products. With these formulas it is possible to calculate stiffness of paper at several levels of fiber orientation.

INFORMATION ACTIVITIES

The sole product of FPL is the information gleaned from its research. As a product, this information is packaged and distributed to potential users in a variety of ways. All printed media, and to a lesser extent radio, television, and motion pictures, are employed. As far as possible, papers are presented in person by staff members to groups ranging from international scientific organizations to community clubs. And, of course, information is dispensed world-wide to visitors and by mail, telephone, and telegraph.

The year 1965 saw all media put to use. A total of 136 printed documents, a list of which follows this section, were issued. Staff members attended 115 formal meetings in the United States and 11 abroad, while 15 technical and scientific groups met at FPL. At these meetings, 59 papers were presented. Sixty-one news and feature releases were prepared and distributed to newspapers, radio, television, and trade and technical journals.

Major group meetings at FPL were:

Representatives of the National Forest Products Association (formerly National Lumber Manufacturers Association), American Institute of Timber Construction, and American Wood-Preservers Association, January 26-27, to discuss strength and moisture sorption characteristics and gluing properties of fire-retardant-treated wood.

Hardwood Action Council, February 3-4.

Lumber-Coating Industries Workshop Conference sponsored by FPL and NFPA, March 8-9.

Representatives of Southern Pine Inspection Bureau, March 10-12.

Research specialists of Weyerhaeuser Company, March 15-16.

Industry Committee on Wood Fiber and Particle Panel Materials, April 22-23 and October 21-22.

Symposium on Density as a Key to Wood Quality, May 4-6.

Research Review Committee, Pulp Chemicals Association, May 25.

Forest Service engineers June 7-8, regarding design, construction, and maintenance of National Forest structures.

Meeting on revision of Federal Test Methods Standard 101, on packaging, attended by representatives of Naval Engineering Standards Office, Air Force Packaging Evaluation Agency, and Bureau of Naval Weapons.

Military Handbooks 17 and 23 Working Groups, representing Air Force, Navy, and Federal Aviation Agency, August 11-12.

Committee D-10 on Packaging, American Society for Testing and Materials, September 21-23.

National Forest Products Association Subcommittee on Technical Studies, October 6-8.

Wood Flooring Institute of America, October 14.



An electron micrograph of wood structure is discussed by Dr. Irving Sachs, right, with Dr. Julius Speer, left, president of the German Research Association, and Alan D. Freas, assistant to the director of FPL. M 129 364

Representatives of Western Forest Industries Association and West Coast Lumber Inspection Bureau, December 14-15.

Forest Biology Conference, sponsored by Technical Association of the Pulp and Paper Industry, November 1-3.

Research Liaison Committee of American Paper Institute and Technical Association of the Pulp and Paper Industry, November 9-10.

Technical Meetings

Papers presented to meetings elsewhere in the United States included six by Director Edward G. Locke. He addressed a Southern Pine Plywood seminar at Meridian, Miss., January 12; Virginia Forests, Inc. January 20 at Williamsburg, Va.; the American Institute of Timber Construction annual meeting at New Orleans February 17; a seminar at the Lake States Forest Experiment Station at St. Paul, Minn., April 15; the American Plywood Association June 14 at Salem, Oreg.; and the National Particleboard Association at Chicago July 7.

Six staff members presented papers at the annual meeting of the Forest Products Research Society in New York June 28-July 1. Other national organizations

at which papers were presented included the American Chemical Society, the Technical Association of the Pulp and Paper Industry, the National Wooden Pallet Manufacturers Association, the American Society of Civil Engineers, the National Forest Products Association Conference, and the American Wood-Preservers Association annual meeting. Alan D. Freas, Assistant to the Director, served as technical adviser to the American Lumber Standards Committee in several deliberative meetings concerning revision of softwood lumber size standards and associated moisture content and shrinkage problems.

Important international meetings included the sessions of Section 41, Forest Products, of the International Union of Forestry Research Organizations at Melbourne, Australia, presided over by Dr. Locke as Section chairman; the United Nations Conference on Pulp and Paper Development in Africa and the Near East attended by G. H. Chidester, chief of FPL's Division of Wood Fiber Products Research, as a consultant; a meeting of the Permanent Committee of IUFRO at Ottawa, Canada, September 9-11, attended by Mr. Freas as Dr. Locke's representative; and an international symposium on Consolidation of the Paper Web at Cambridge, England, September 20-24, attended by F. A. Simmonds, pulp and paper chemist.

Visitors

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Prominent among foreign visitors to FPL were Dr. Julius Speer, President of the German Research Association and of IUFRO, and a professor of forestry at the University of Munich, and Dr. Lincoln Thiesmeyer, president of the Pulp and Paper Research Institute of Canada, Montreal. Dr. Thiesmeyer addressed the staff April 21 on "What's Ahead in Pulp and Paper." A delegation of the European Particle Board Manufacturers Association came September 21, and a study team of the Japanese Society of Polymer Science, Tokyo, was here October 6. In all, 45 foreign Nations sent citizens for consultation.

Forty-seven States and two territories were represented in FPL's visitor records for the year.

The 1965 total of all visitors was 11,970, up 208 from 11,762 the previous year. Of these, 3,811 were consulting visitors seeking advice and guidance on specific problems.

Educational Activities

Two staff members returned from research assignments abroad, and a third spent a 6-month period overseas. Dr. Milton S. Feather completed a year's research on carbohydrate chemistry at the Swedish Forest Products Laboratory, Stockholm, under authorization of Public Law 85-807. Dr. Catherine Duncan did pathological research on fungal decay at a Swiss institute in Zurich for 18 months, in part financed under Public Law 85-807 and in part by a National Science Foundation Fellowship. Dr. Richard F. Blomquist did plywood research on a senior research fellowship of the New



A research job involving studies of heat loss from wood surfaces occupied the summer for Dallas Wingo, Clark College junior from Atlanta, Ga., one of 20 summer undergraduate employees.

Zealand Forest Service at the Forestry Research Institute at Rotorua.

Seven University of Wisconsin graduate students were employed as research associates to do work for their advanced degrees under the cooperative agreement with the University which has been in effect since FPL was established in 1910.

Whitten Act Grants

Whitten Act funds provided research grants for 13 graduate students at various institutions. A study on wood machining with water jets was continued at the University of Michigan. At the University of California an investigation into the effects of environmental and other conditions on formation of summerwood and springwood was concluded, while another on chemical analysis of resin acids obtained from rosin of pine stumpwood was continued.

Two grants at the University of Minnesota were continued for (1) evaluation of the size and distribution of intertracheid pores in conifers and (2) factors involving initial infection of wood by fungi. Work on the catalytic hydrogenation of lignin during pulping with aqueous alkali and organic solvents was continued

at the State University of New York at Syracuse, and a new grant was made for research on effects of transverse stress on equilibrium moisture content of wood.

A study of the effects of soil fertilizer on specific gravity and fiber properties was supported by a grant at Iowa State University. At Michigan Technological University, a study was begun of the stability of semi-rigid glue bonds under varying temperatures and humidities. A grant for study of the effect of pulping and bleaching on lignin was awarded the University of Washington.

Two grants were made to Oregon State University, one for research on detecting rot in standing timber by sonic waves, and the other to obtain preliminary data on effects of creep in prestressed laminated beams. A grant to Southern Illinois University to study reaction rates of polysaccharides in alkaline solutions was continued.

Undergraduate Summer Trainees

Twenty undergraduate college students, selected from a field of 114 applicants, spent the summer at FPL working on research projects as technical aids. The purpose of this program is to acquaint promising science and engineering students with the opportunities in forest products research. They came from Utah

State, Fisk, Oregon State, South Dakota State, Iowa State, and Colorado State Universities; the Universities of Massachusetts, Illinois, Wisconsin, and West Virginia; from Grinnell, Ripon, Reed, Portland State, and Clark Colleges; and from Louisiana Polytechnic Institute, the State University of New York, and Wisconsin State University at Eau Claire.

Exhibits

Four exhibits delineating aspects of FPL research were prepared and put on display during the year. One was shown at the Southern Pine Association's eighth Sawmill Machinery and Equipment Exposition April 3-5 at New Orleans. Another was shown at the Iowa State University College of Forestry in May. Others were on display at the Wisconsin State Fair August 13-22 and the annual meeting of the Society of American Foresters in Detroit October 25-27.

FPL was also the 1-day site of an exhibit touring the United States on behalf of the Canadian Hardwood Plywood Association and Canadian Department of Trade and Commerce. It featured birch, both the wood and the winner of a Miss Canadian Birch contest. For the occasion Donald H. Cheney, Canadian Consul at Chicago, and his assistant, Clark Leith, came to FPL.

An automobile, a model, and electronic specialist John A. Waldvogel demonstrated to Wisconsin State Fairgoers the strength and stiffness of Fiberneer, FPL-developed combination of container fiberboard and veneer for boxes. M 129 129



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